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Simulated Effects of Ground-Water Management Scenarios on the Santa Fe Group Aquifer System, Middle Rio Grande Basin, New Mexico, 2001-40

By Laura M. Bexfield and Douglas P. McAda

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Multiply	By	To obtain
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
square mile (mi^2)	259.0	hectare (ha)
square mile (mi^2)	2.590	square kilometer (km^2)
acre-foot (acre-ft)	1,233	cubic meter (m^3)
acre-foot (acre-ft)	0.001233	cubic hectometer (hm^3)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
acre-foot per year (acre-ft/yr)	1,233	cubic meter per year (m^3/y)
foot per day (ft/d)	0.3048	meter per day (m/d)

Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD 88).

Altitude, as used in this report, refers to distance above or below sea level.

SIMULATED EFFECTS OF GROUND-WATER MANAGEMENT SCENARIOS ON THE SANTA FE GROUP AQUIFER SYSTEM, MIDDLE RIO GRANDE BASIN, NEW MEXICO, 2001-40

By Laura M. Bexfield and Douglas P. McAda

ABSTRACT

Future conditions in the Santa Fe Group aquifer system through 2040 were simulated using the most recent revision of the U.S. Geological Survey ground-water-flow model for the Middle Rio Grande Basin. Three simulations were performed to investigate the likely effects of different scenarios of future ground-water pumping by the City of Albuquerque on the ground-water system. For simulation I, pumping was held constant at known year-2000 rates. For simulation II, pumping was increased to simulate the use of pumping to meet all projected city water demand through 2040. For simulation III, pumping was reduced in accordance with a plan by the City of Albuquerque to use surface water to meet most of the projected water demand. The simulations indicate that for each of the three pumping scenarios, substantial additional water-table declines would occur in some areas of the basin through 2040. However, the reduced pumping scenario of simulation III also results in water-table rise over a broad area of the city. All three scenarios indicate that the contributions of aquifer storage and river leakage to the ground-water system would change between 2000 and 2040.

Comparisons among the results for simulations I, II, and III indicate that the various pumping scenarios have substantially different effects on water-level declines in the Albuquerque area and on the contribution of each water-budget component to the total budget for the ground-water system. Between 2000 and 2040, water-level declines for continued pumping at year-2000 rates are as much as 120 feet greater than for reduced pumping; water-level declines for increased pumping to meet all projected city demand are as much as 160 feet greater. Over the same time period, reduced pumping results in retention in aquifer storage of about 1,536,000 acre-feet of ground water as compared with continued pumping at year-2000 rates and of about 2,257,000 acre-feet as compared with increased pumping. The quantity of water retained in the Rio Grande as a result of reduced pumping and the associated decrease in induced recharge from the river is about 731,000 acre-feet as compared with continued pumping at year-2000 rates and about 872,000 acre-feet as compared with increased pumping. Reduced pumping results in slight increases in the quantity of water lost from the ground-water system to evapotranspiration and agricultural-drain flow compared with the other pumping scenarios.

INTRODUCTION

The City of Albuquerque, located in the Middle Rio Grande Basin (otherwise known as the Albuquerque Basin) of central New Mexico, historically has obtained all its municipal-supply water from wells completed in the sediments of the Santa Fe Group aquifer system. Ground-water pumping by the City of Albuquerque for municipal supply has totaled more than 100,000 acre-feet, and as much as 126,600 acre-feet, every year since 1986 (files of the City of Albuquerque). As a result of pumping by the City of Albuquerque and other water users in the region, water levels in parts of the aquifer system have declined by more than 120 feet (Bexfield and Anderholm, 2002). Because of the limited availability of ground water for future municipal supply, the City of Albuquerque currently (2002) is in the process of implementing a plan to reduce well pumping by diverting much of its municipal-supply water from the Rio Grande. Most of the water taken from the river will be associated with the San Juan-Chama Diversion Project. The city owns rights to 48,200 acre-feet of water per year from the project, by which water is imported from the Colorado River Basin into the Rio Grande Basin and stored in reservoirs upstream from the city. Although the planned surface-water diversions will meet much of the city's present demand for water, ground-water pumping will be required to supplement water supplies during periods of large demand or drought.

The shift in the primary source of municipal supply for the City of Albuquerque from ground water to surface water will have significant consequences for the river-aquifer system. Estimates of these consequences are needed to aid in the city's implementation of long-term water-management strategies that will benefit regional water users and the hydrologic system as a whole. The ground-water-flow model developed by McAda and Barroll (2002) for the Middle Rio Grande Basin, hereafter referred to as the McAda and Barroll model, was used in this study to evaluate the consequences of potential water-management strategies on components of the hydrologic system such as aquifer storage and river leakage. This study was performed in cooperation with the City of Albuquerque.

Purpose and Scope

This report presents results of ground-water flow-model simulations designed to compare and contrast the effects of potential water-management strategies by the City of Albuquerque on components of the river-aquifer system of the Middle Rio Grande Basin. Three scenarios of large, medium, and small rates of ground-water pumping by the City of Albuquerque from 2001 through 2040 were simulated using the McAda and Barroll model for the basin. This report evaluates and compares the resulting water levels and water budgets for the entire Middle Rio Grande Basin, with emphasis on the Albuquerque area.

Previous Investigations

The Middle Rio Grande Basin between Cochiti Lake and San Acacia has been the subject of numerous hydrogeologic investigations and ground-water-flow models. The current study uses the most recent ground-water-flow model for the basin, which was developed by McAda and Barroll (2002). Previous models developed for the basin include those by Kernodle and others (1995), Kernodle (1998), Tiedeman and others (1998), and Barroll (2001). These previous models were based principally on a conceptual model of the basin as defined by Thorn and others (1993), which incorporated geologic information from Kelley (1977), Lozinsky (1988), and Russell and Snelson (1990); hydrogeologic information from Hawley and Haase (1992); and hydrologic information from Bjorklund and Maxwell (1961). The McAda and Barroll model incorporates additional knowledge gained primarily through a series of investigations started in 1995 as part of a focused effort by the U.S. Geological Survey (USGS) and other Federal, State, and local agencies to improve knowledge of the hydrogeology of the Middle Rio Grande Basin. Recent geologic, hydrologic, and hydrochemical investigations that contributed substantially to the latest revision of the ground-water-flow model are described in McAda and Barroll (2002). All investigations included in the recent focused effort on the basin are detailed in Bartolino and Cole (2002) and in collections of extended abstracts edited by Bartolino (1997), Slate (1998), Bartolino (1999), and Cole (2001).

Description of the Study Area

Bartolino and Cole (2002) and Thorn and others (1993), among others, provided thorough descriptions of the Middle Rio Grande Basin. Therefore, only a brief description of the study area is provided here, and the reader is referred to those publications for additional detail. The Middle Rio Grande Basin of central New Mexico (fig. 1) is one of a series of physiographic basins located in the Rio Grande Rift. The basin covers about 3,060 square miles and is bounded by mountains reaching altitudes as high as about 11,000 feet along most of the northern, eastern, and southern margins and by more subdued uplifts along the western margin.

The primary aquifer within the Middle Rio Grande Basin is the Santa Fe Group aquifer system, which exceeds 10,000 feet in thickness in places and includes Santa Fe Group deposits of late Oligocene to middle Pleistocene age and the hydrologically connected post-Santa Fe Group alluvium of Pleistocene to Holocene age. Sediments of the Santa Fe Group are divided into lower, middle, and upper sections, of which the upper section is the most permeable.

The climate of the Middle Rio Grande Basin is semiarid, with large evapotranspiration relative to precipitation, so most recharge to the aquifer system occurs either along basin margins as mountain-front recharge and ground-water inflow or within the basin as infiltration through streams (Thorn and others, 1993; Kernodle and others, 1995). The Rio Grande is the main surface drainage for the basin. The Rio Grande is bordered by an inner valley, or flood plain, that is as much as 6 miles wide and includes a system of irrigation canals and drains that support agriculture. The Rio Puerco and other ephemeral streams in the

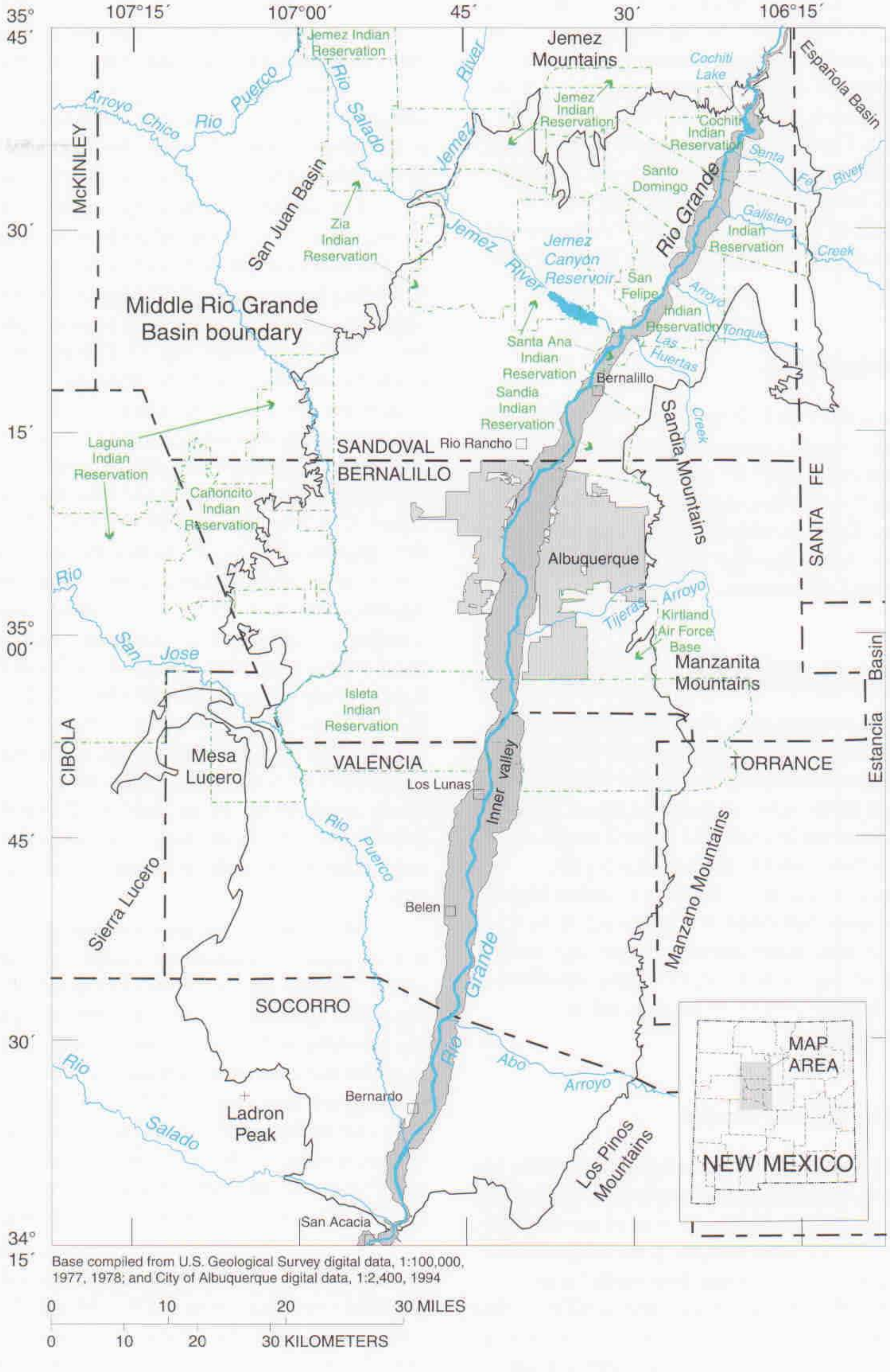

Figure 1. Location of the Middle Rio Grande Basin, central New Mexico.

basin also contribute recharge to the aquifer. Some ground water flows from the Middle Rio Grande Basin south to the Socorro Basin, but most discharge occurs through pumping, evapotranspiration in the inner valley, or flow into drains and gaining sections of the Rio Grande (Thorn and others, 1993; Kernodle and others, 1995). The City of Albuquerque is the largest user of ground water in the basin. The city supplied more than 475,000 people in 2001, using 92 of its municipal-supply wells (fig. 2) (City of Albuquerque, 2002), which are described in detail in Bexfield and others (1999).

Acknowledgments

The authors thank Greg Gates with CH2M Hill for providing the projections of total water demand and surface-water availability for the City of Albuquerque that were used in this investigation. The authors also thank Wesley Danskin with the USGS and John Stomp with the City of Albuquerque for consulting on the design of model simulations.

DESIGN OF MODEL SIMULATIONS

For this investigation, the McAda and Barroll ground-water-flow model was used with only minor modification to simulate conditions through 2000. For 2000 through 2040, many of the most recent input parameters from the McAda and Barroll model were duplicated without modification for each year, although input for the Rio Grande was varied among years in a manner described in a following section. Projections of total water demand and ground-water compared to surface-water supply for the simulated years 2000 through 2040 also are detailed in a subsequent section.

McAda and Barroll Model

The McAda and Barroll model of the Middle Rio Grande Basin simulates ground-water flow in the Santa Fe Group aquifer system over an area of about 2,350 square miles. This model uses the three-dimensional, finite-difference, ground-water-flow model code MODFLOW-2000 (Harbaugh and others, 2000), with a slight modification in the Layer Property Flow package to the calculation of vertical leakage under certain conditions, as described by McAda and Barroll (2002). The McAda and Barroll model was developed to (1) integrate the components of the ground-water-flow system, including hydrologic interaction between the ground- and surface-water systems in the basin, to better understand the geohydrology of the basin and (2) provide a tool for water managers to plan and administer the use of basin water resources. The model is described only briefly here, and the reader is referred to McAda and Barroll (2002) for more detail.

The aquifer system is represented in the model by nine layers (fig. 3) extending from the water table to the pre-Santa Fe Group basement rocks, as much as 9,000 feet below sea level. The horizontal grid contains 156 rows and 80 columns, each equally spaced 3,281 feet (1 kilometer) apart (fig. 4). The grid is oriented north-south to align with the principal directions of anisotropy. Layers 1-5 are variable in thickness over the model area, depending on the altitude of the steady-state simulated water table relative to the altitude of the Rio Grande (fig. 3). The steady-state thicknesses of layers 1, 2, 3, 4, and 5 are 30, 50, 100, 220, and 400 feet, respectively, directly below the Rio Grande and vary in proportionate dimensions (either larger or smaller) elsewhere. Layer 1 is relatively thin to simulate ground-water/surface-water interaction in the inner valley. Layer 6 is a constant 600 feet thick and layer 7 is a constant 1,000 feet thick. Cells in layers 1-7 are active where the center of the cell is higher in altitude than the base of the Santa Fe Group. The thicknesses of layers 8 and 9 are one-third and two-thirds, respectively, of the Santa Fe Group thickness below layer 7. Cells in model layers 8 and 9 are active only where their combined thickness is at least 1,200 feet.

Model layers 1-4 are represented as convertible from confined to unconfined conditions (Harbaugh and others, 2000)—that is, active cells in which the simulated hydraulic head is above the designated layer top are simulated under confined conditions, and cells in which the simulated hydraulic head is below the layer top are simulated under water-table conditions. This convertible condition allows the simulated water table to transfer to the next lower cell as simulated water levels decline below the bottom of a cell. Model layers 5-9 are represented as always confined.

The McAda and Barroll model simulates predevelopment steady-state conditions and historical transient conditions from 1900 to March 2000 in 1 steady-state and 52 historical stress periods. Average annual conditions are simulated prior to 1990, and seasonal (winter and irrigation season) conditions are simulated from 1990 to March 2000.

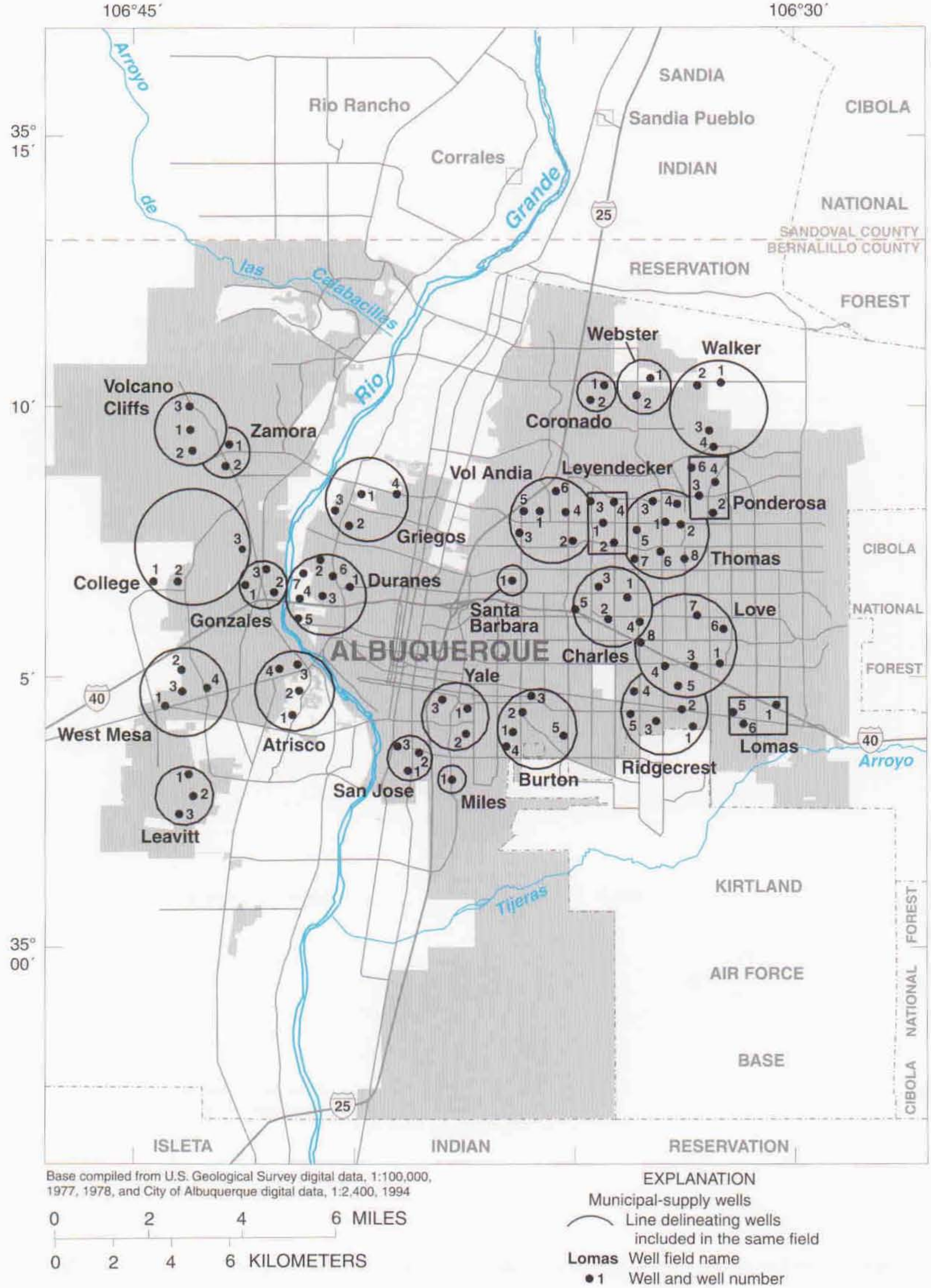

Figure 2. City of Albuquerque municipal-supply wells.

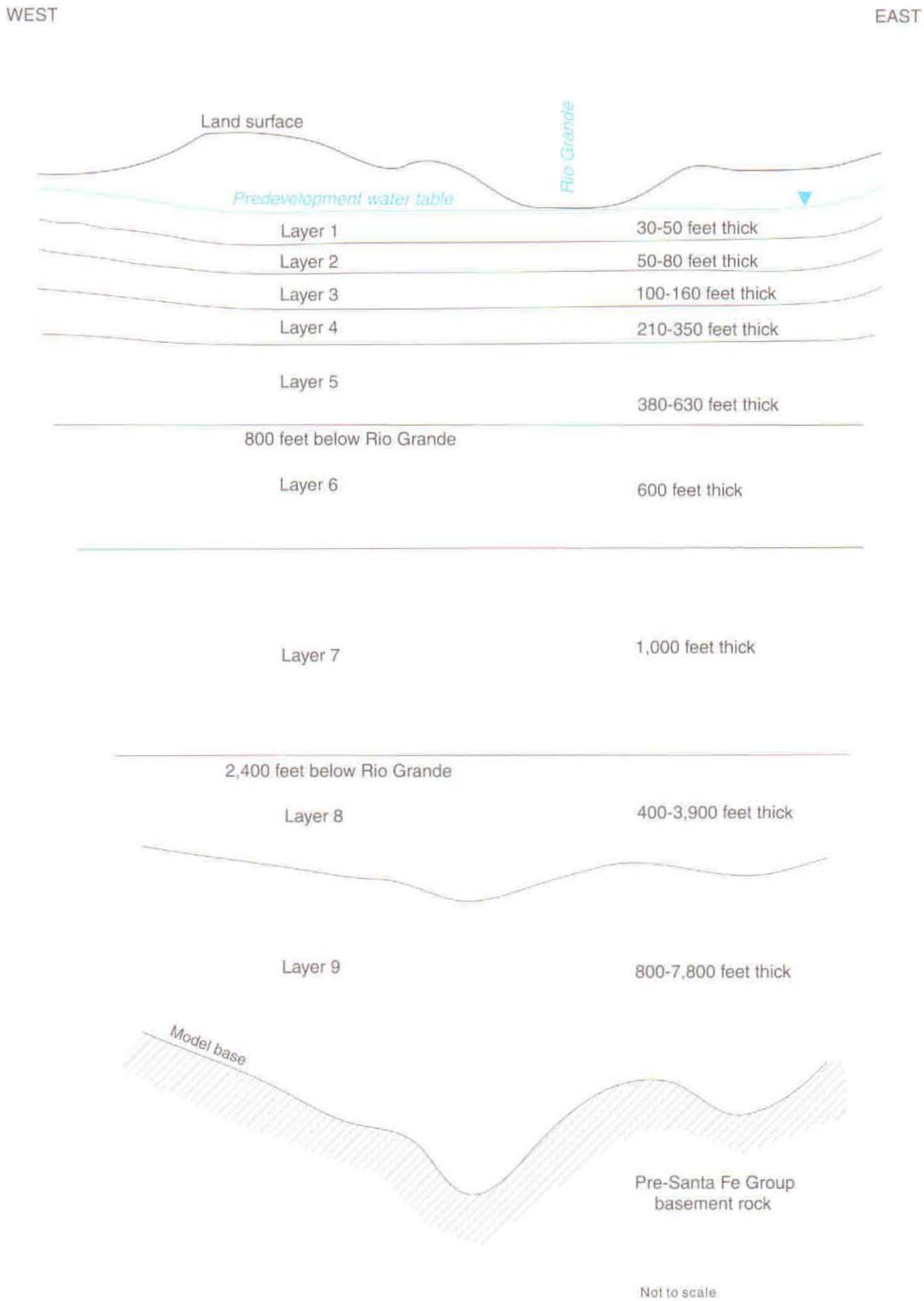

Figure 3. Configuration of layers in the model. Modified from McAda and Barroll (2002, fig. 8).

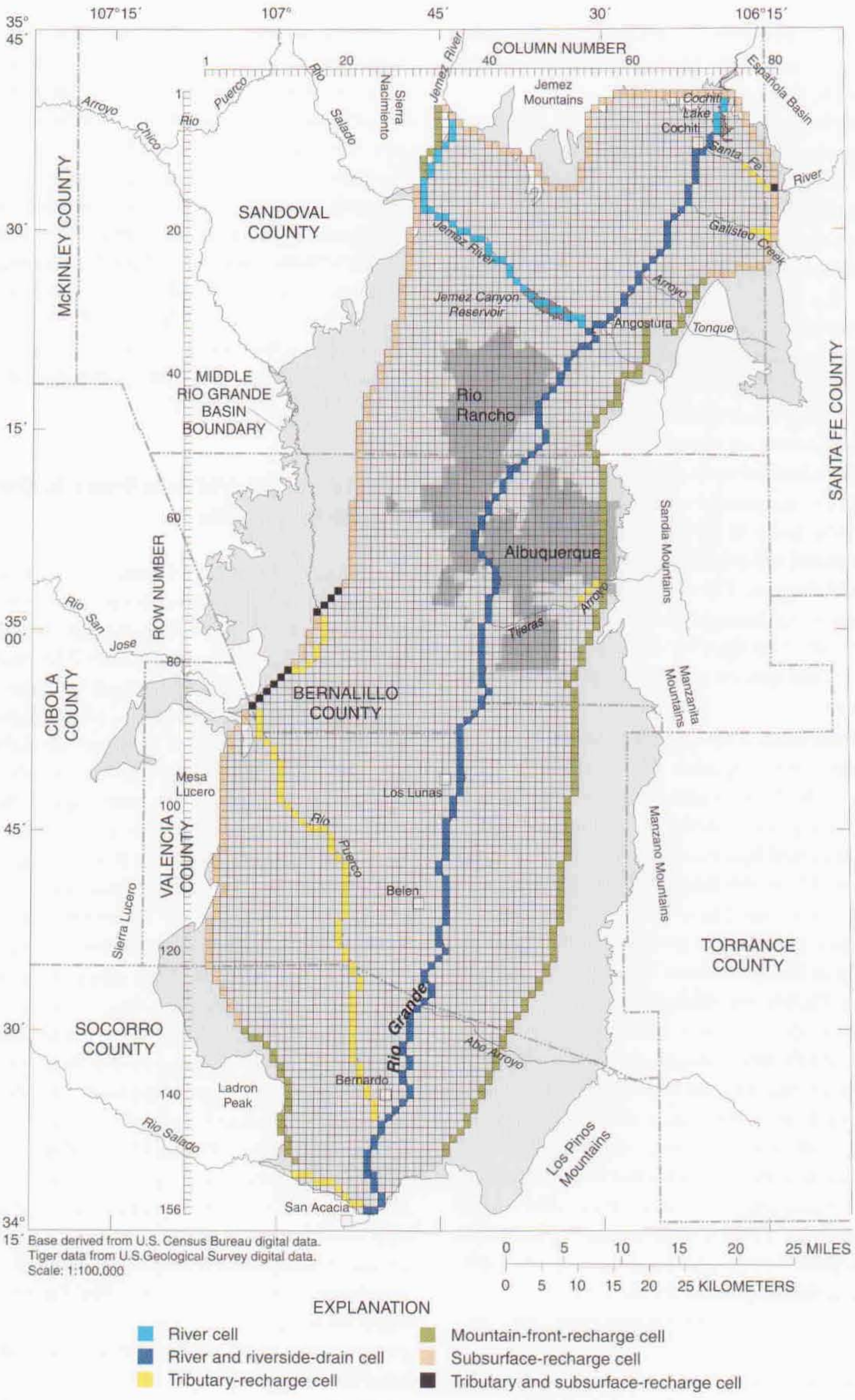

Figure 4. Model grid and active model cells in layer 1. From McAda and Barroll (2002, fig. 7).

Hydrologic properties representing the Santa Fe Group aquifer system in the McAda and Barroll model are horizontal hydraulic conductivity, vertical hydraulic conductivity, specific storage, and specific yield. The aquifer system is simulated to be horizontally and vertically anisotropic—that is, hydraulic conductivities along the three axes of the model are not necessarily equal. The horizontal hydraulic conductivity in the east-west direction (along model rows; K_x) of the model ranges from 0.05 to 45 ft/d. The hydraulic conductivity in the north-south direction (along model columns; K_y) of the model ranges from 0.05 to 60 ft/d. The horizontal anisotropy ratio (K_y / K_x) varies over the model domain from 1:1 to 5:1. Selected faults are simulated as horizontal flow barriers, which simulate reduced hydraulic conductivity between model cells. The vertical hydraulic conductivity in the model is simulated by applying a vertical anisotropy ratio (K_x / K_z) of 150:1 over the model domain. This results in simulated vertical hydraulic-conductivity values ranging from 3×10^{-4} to 3×10^{-1} ft/d. Specific storage is simulated to be 2×10^{-6} ft^{-1} and specific yield is simulated to be 0.2 (dimensionless).

Mountain-front, tributary, and subsurface recharge; canal, crop-irrigation, and septic-field seepage; and ground-water withdrawal are simulated as specified-flux boundaries in the McAda and Barroll model. At a specified-flux boundary, water is recharged to or discharged from the simulated aquifer system independent of simulated head in the aquifer. The specified fluxes in the model are simulated to pass to the next lower cell if the cell in which a flux is assigned goes dry (see McAda and Barroll, 2002, for modifications made to the well package of the MODFLOW-2000 code). Mountain-front, tributary, and subsurface recharge from adjacent ground-water basins are specified to be constant throughout the simulation period, whereas canal, crop-irrigation, and septic-field seepage and ground-water withdrawal vary through the simulation period on the basis of historical data. Ground-water withdrawal from major production wells with screened intervals spanning several model layers, such as those operated by the City of Albuquerque, is divided among layers depending on the proportion of screen length in each layer. These major production wells typically withdraw water from some combination of layers 4 through 6, with most withdrawal from layer 5.

The Rio Grande, riverside drains, interior drains, Jemez River, Jemez Canyon Reservoir, Cochiti Lake, and riparian evapotranspiration are simulated in the model as head-dependent flux boundaries. At a head-dependent flux boundary, water is recharged or discharged as a function of simulated hydraulic head in the aquifer system and specified information for the boundary, such as a specified river stage or a specified evapotranspiration surface. Specified boundary information varies through the simulation period on the basis of historical data. The head-dependent flux boundaries in the model can be used to estimate the effects of changes in aquifer-system stresses on the fluxes at these boundaries.

Modifications and Additions to the McAda and Barroll Model

To simulate future conditions in the Middle Rio Grande Basin under various scenarios of ground-water pumping by the City of Albuquerque, operation of the McAda and Barroll model through 2000 was modified slightly. Two City of Albuquerque municipal-supply wells, Gonzales 3 and Zamora 2 (fig. 2), which were brought online in 1999 and 1998, respectively, were not included in the original model. Because these wells were projected to pump substantial quantities of water during the time period of interest, they were added into the model beginning with the years during which they first produced water that was delivered to city customers. Also, layer 5 of the model was assigned to be convertible from confined to unconfined conditions.

For 2000 through 2040, many of the most recent parameters input to the McAda and Barroll model were duplicated without modification. These parameters included those for mountain-front recharge, tributary recharge, underflow, recharge from irrigation (generally 1992 data), recharge from septic-tank effluent (based on 1990 population data), drain conditions, and evapotranspiration conditions. With the exception of City of Albuquerque data, the most recent data available in the McAda and Barroll model for ground-water pumping also were included in all model simulations for each year from 2000 through 2040. For major municipal and commercial pumping, the pumping data used generally were from 2000, except where 1999 data were the most recent available. Data for these years did not appear anomalously high or low compared with data for previous years. The use of domestic-well pumping based on 1990 population data also was continued. No attempt was made to simulate future changes in pumping from wells other than those operated by the City of Albuquerque because future pumping by such wells is not the focus of this study, is subject to multiple uncertainties, and is small by comparison.

City of Albuquerque ground-water pumping between 2000 and 2040 differed among three different model simulations intended to represent scenarios of small, medium, and large ground-water use. For simulation I, ground-water pumping in all city municipal-supply wells was maintained at known year-2000 rates for each year through 2040 (fig. 5), representing medium ground-water use. Year-2000 pumping data were used rather than an average of recent years because some older wells were retired and newer wells were brought online in the late 1990's; year-2000 data were not anomalously large or small compared with data for other recent years.

For simulation II (representing large ground-water use), city pumping was adjusted to simulate the use of ground-water pumping to meet all projected water demand, which is expected to rise substantially through 2040. Annual projections of future water demand were obtained from Greg Gates (CH2M Hill, written commun., 2001), consultant to the City of Albuquerque. The projections of future demand were input to the model by applying individual multipliers for each future year and season to the known year-2000 pumping data. In essence, these multipliers represent the ratio of total projected demand during each future year to total pumping during the year 2000. However, because the winter season used in the model is defined to extend across 2 years (from November of one year to mid-March of the following year), the winter multipliers had to be adjusted to take into account the annual projections of both years. Therefore, multipliers were calculated as follows:

For simulation III (representing small ground-water use), city pumping was adjusted to match projections by Greg Gates (written commun., 2001) of future ground-water use that assume surface water is available to meet much of the total water demand, resulting in decreased pumping (fig. 5). These projections take weather cycles into account to determine the likely availability of surface water in any given year. As for simulation II, the ground-water pumping projections were translated into the model by calculating multipliers that were applied to year-2000 pumping for each year and season. Equations 1 and 2 were again used, except that "total projected ground-water pumping" was substituted for "total projected demand" for each future year, y or (y+1).

For all model simulations, conditions in the Rio Grande were varied for each year between 2006 (the year that surface water is anticipated to be available for delivery to City of Albuquerque customers) and 2040 to match the weather cycles that Greg Gates (written commun., 2001) assumed in determination of ground-water pumping projections. Greg Gates used historical streamflow data for selected average, wet, and dry years to calculate the potential availability of surface water in each year from 2006 to 2040, depending on the weather conditions assumed for that year. For this investigation, the 25th and 75th percentiles of streamflow were calculated from the same streamflow data used by Greg Gates (written commun., 2001). For each of the three divisions of streamflow data (data up to the 25th percentile, data between the 25th and 75th percentiles, and data above the 75th percentile), "average" river conditions within that division were determined. These conditions were then used to establish "typical" wet, dry, and normal configurations of the Rio Grande for use in the model. The configuration used in the model for any given year was chosen to match the approximate weather conditions and associated surface-water availability assumed by Greg Gates (written commun., 2001) for that year.

$$\text{Multiplier for summer pumping in year y} = \frac{\text{Total projected demand in year y}}{\text{Total pumping in 2000}} \quad (1)$$

$$\text{Multiplier for winter pumping year y to (y+1)} = \frac{\text{Number of winter days in year y}}{\text{Total number of winter days}} \times \frac{\text{Total projected demand in year y}}{\text{Total pumping in 2000}} + \frac{\text{Number of winter days in year (y+1)}}{\text{Total number of winter days}} \times \frac{\text{Total projected demand in year (y+1)}}{\text{Total pumping in 2000}} \quad (2)$$

The resulting increases in pumping for simulation II are shown in figure 5.

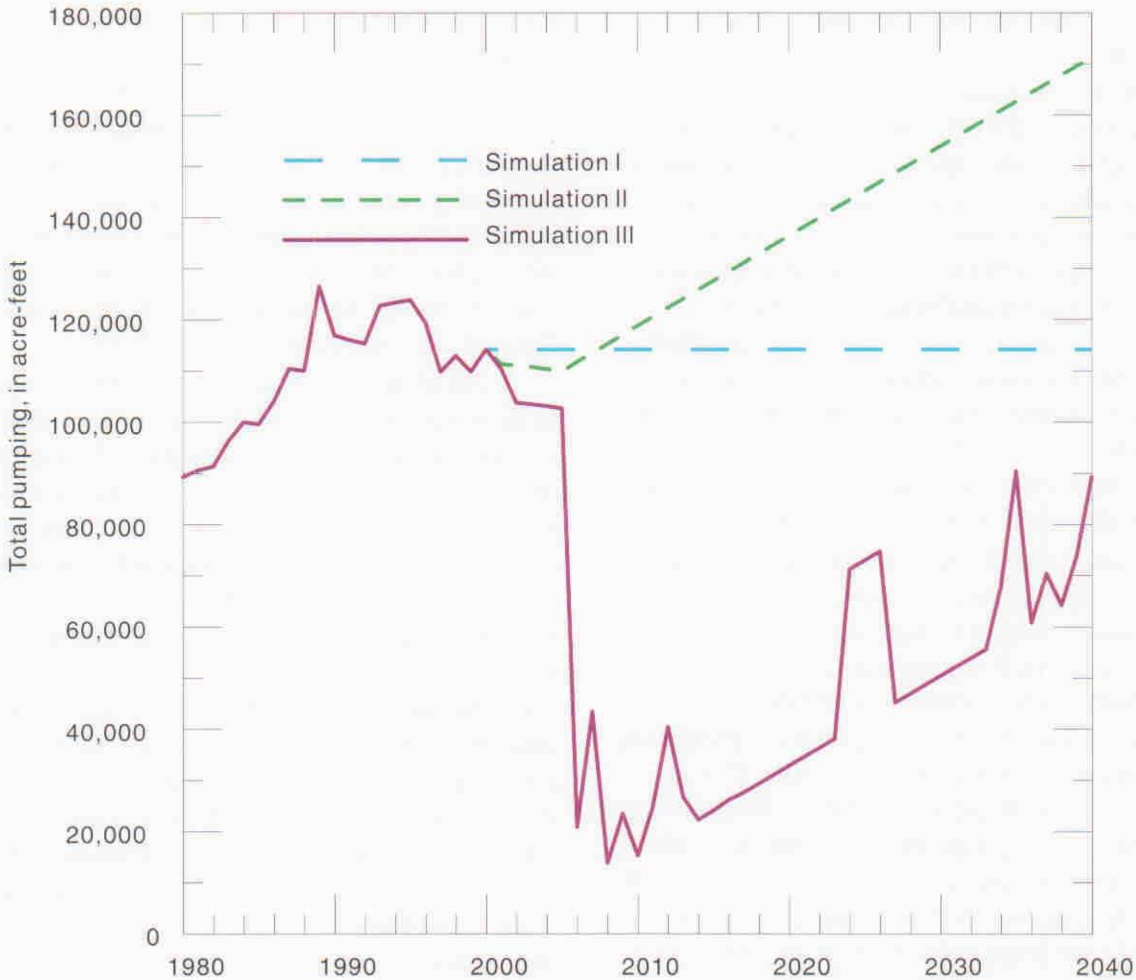

Figure 5. Annual City of Albuquerque pumping assigned for each model simulation, 1980 to 2040.

SIMULATED EFFECTS OF GROUND-WATER MANAGEMENT SCENARIOS

Results of model simulations I, II, and III for scenarios of future ground-water pumping by the City of Albuquerque were examined for changes in simulated water levels and contributions of the various components of the simulated water budget for the aquifer over time. Although results were examined basinwide, emphasis was placed on results in the Albuquerque area, where the most significant changes are expected.

Simulation I—Continued Pumping at Year-2000 Rates

The model indicates that continued pumping at known year-2000 rates through 2040 would add substantially to water-level decline already present in the aquifer in 2000 relative to predevelopment conditions. Additional water-level decline (supplementary to the decline present in 2000) through 2040 is substantial both at the water table and in the production zone of the aquifer. The area of additional water-table decline of at least 5 feet extends from about the Zia and Sandia Indian Reservations on the north to the Isleta Indian Reservation on the south and from almost the western boundary to the eastern boundary of the model, with the exception of areas close to the Rio Grande (fig. 6). The greatest additional water-table decline occurs near the eastern edge of Albuquerque and near the northwestern corner of the city; additional water-table decline of 60 to 100 feet is common in both areas. In the production zone of the aquifer (defined in a previous section as best represented by layer 5 of the model), additional water-level decline extends over a somewhat larger area, but generally is of slightly smaller magnitude (fig. 7). Near the northwestern corner of the city, additional water-level decline in the production zone generally is less than about 60 feet, whereas in the eastern part of the city it generally is less than about 80 feet. This simulation indicates that pumping at year-2000 rates through 2040 results in total water-table decline relative to predevelopment conditions that commonly exceeds 120 feet near the northwestern corner of the city and 200 feet in the eastern part of the city, with maximum decline exceeding 225 feet (fig. 8). Water-level decline in the production zone is of similar magnitude for the same time period. Despite sustained pumping and substantial water-level decline over this extended time period, no model cells at the Rio Grande went dry, indicating that saturated hydraulic connection was never lost between the river and the ground-water system.

Simulation I indicates substantial changes in the water budget of the aquifer between 2000 and 2040 as pumping continues at year-2000 rates. During this period, net river leakage (inflow to the ground-water system from the river minus outflow from the ground-water system to the river) represents an increasing percentage of total inflow to the ground-water system over time as a result of the larger hydraulic gradients created as water levels continue to decline in the aquifer. Net river leakage increases from about 33 to 37 percent of total inflow during the summer and 36 to 44 percent of total inflow during the winter (fig. 9). The actual contribution rate of river leakage to the system during 2000 to 2040 increases by about 12 percent during the summer and 16 percent during the winter (fig. 10a). The percentage contribution of water to the system from net storage (inflow to the ground-water system from storage minus outflow from the ground-water system into storage) during this time period decreases as greater river recharge is induced and the quantity of water available from storage declines. Between 2000 and 2040, the contribution from net storage drops from about 10 to 7 percent of total inflow during the summer and 40 to 30 percent of total inflow during the winter (fig. 9). The actual rate of inflow from storage decreases by about 27 percent during the summer and 28 percent during the winter (fig. 10b). The outflow budget for the 2000-40 period shows that both percentage losses and actual rates of loss through evapotranspiration and drain flow are nearly constant for summer and winter (figs. 9 and 11).

Simulation II—Increased Pumping to Meet All Demand

Simulation II represents the scenario of large pumping by the City of Albuquerque to meet all water demand through 2040. Simulation II results in the same general areal pattern and extent of additional water-level decline (over decline present in 2000) as observed in simulation I; however, the magnitude of additional decline is substantially greater. Between 2000 and 2040, additional decline commonly exceeds 90 feet in the northwestern part of Albuquerque and 120 feet in the eastern part (fig. 12). This simulation indicates that increased pumping through 2040 would result in total water-table decline since predevelopment that commonly exceeds 150 feet near the northwestern corner of the city and 250 feet in the eastern part of the

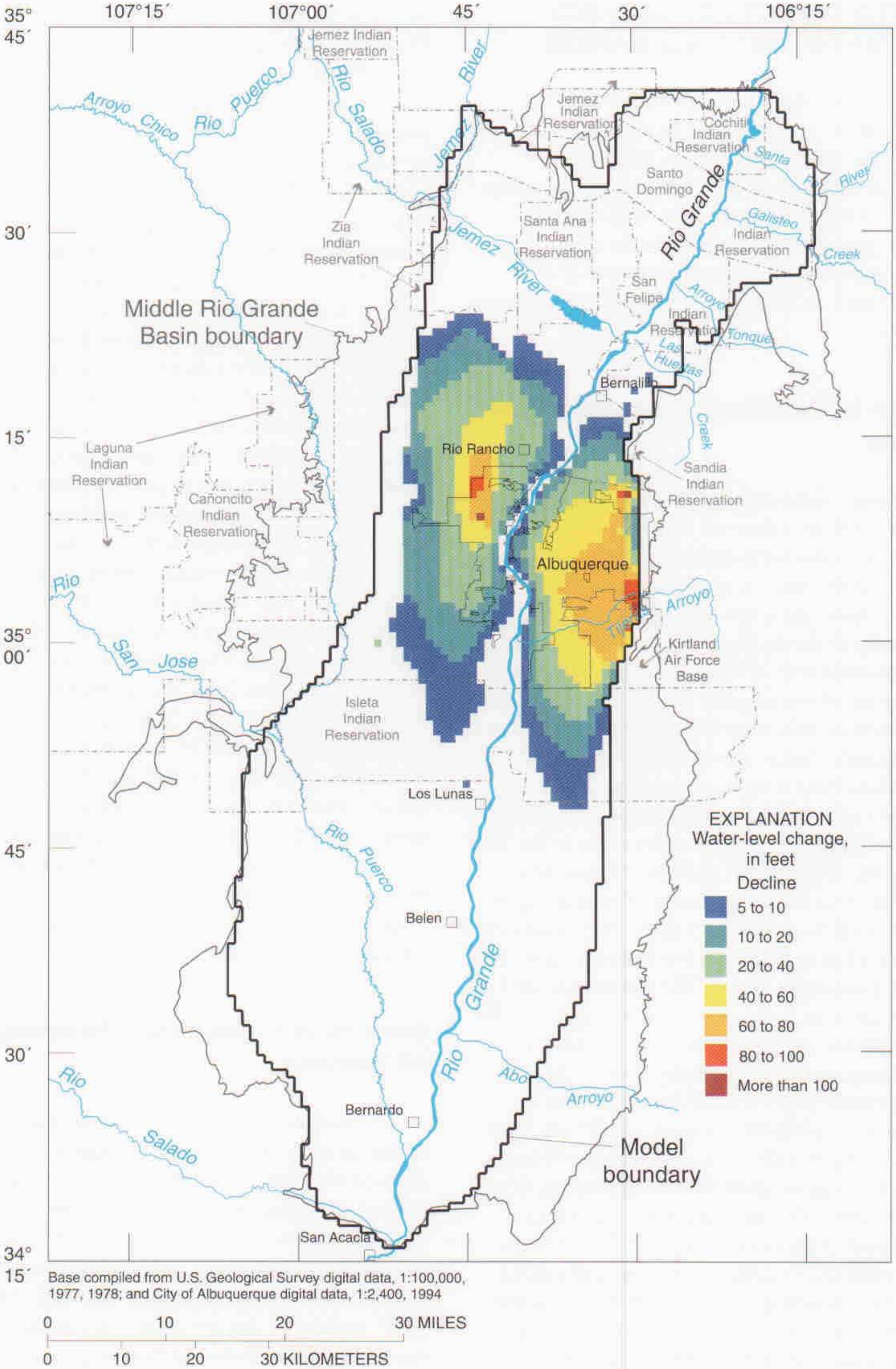

Figure 6. Simulated water-table change in the Middle Rio Grande Basin between 2000 and 2040 for simulation I.

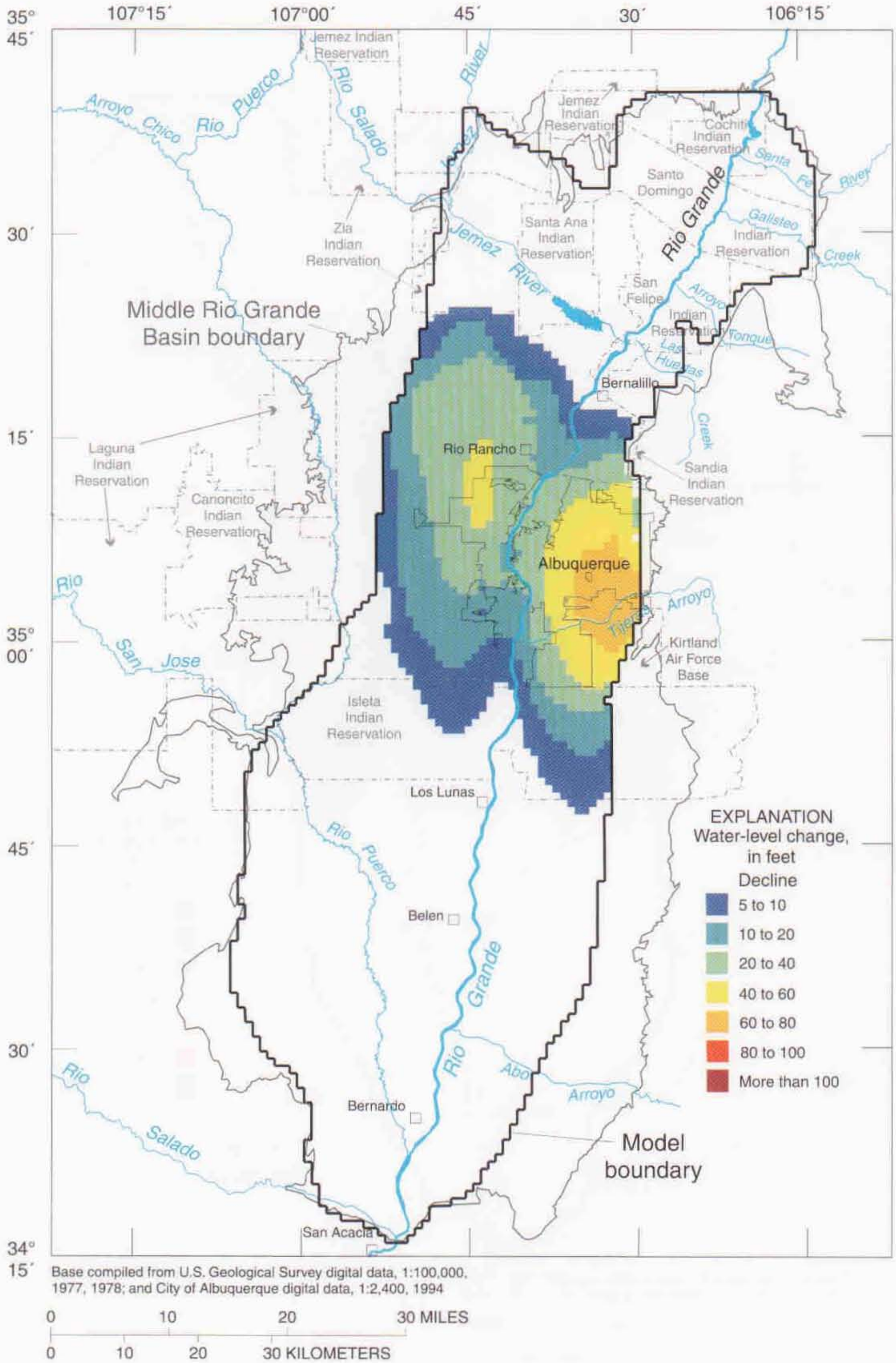

Figure 7. Simulated water-level change in the production zone (layer 5) between 2000 and 2040 for simulation I.

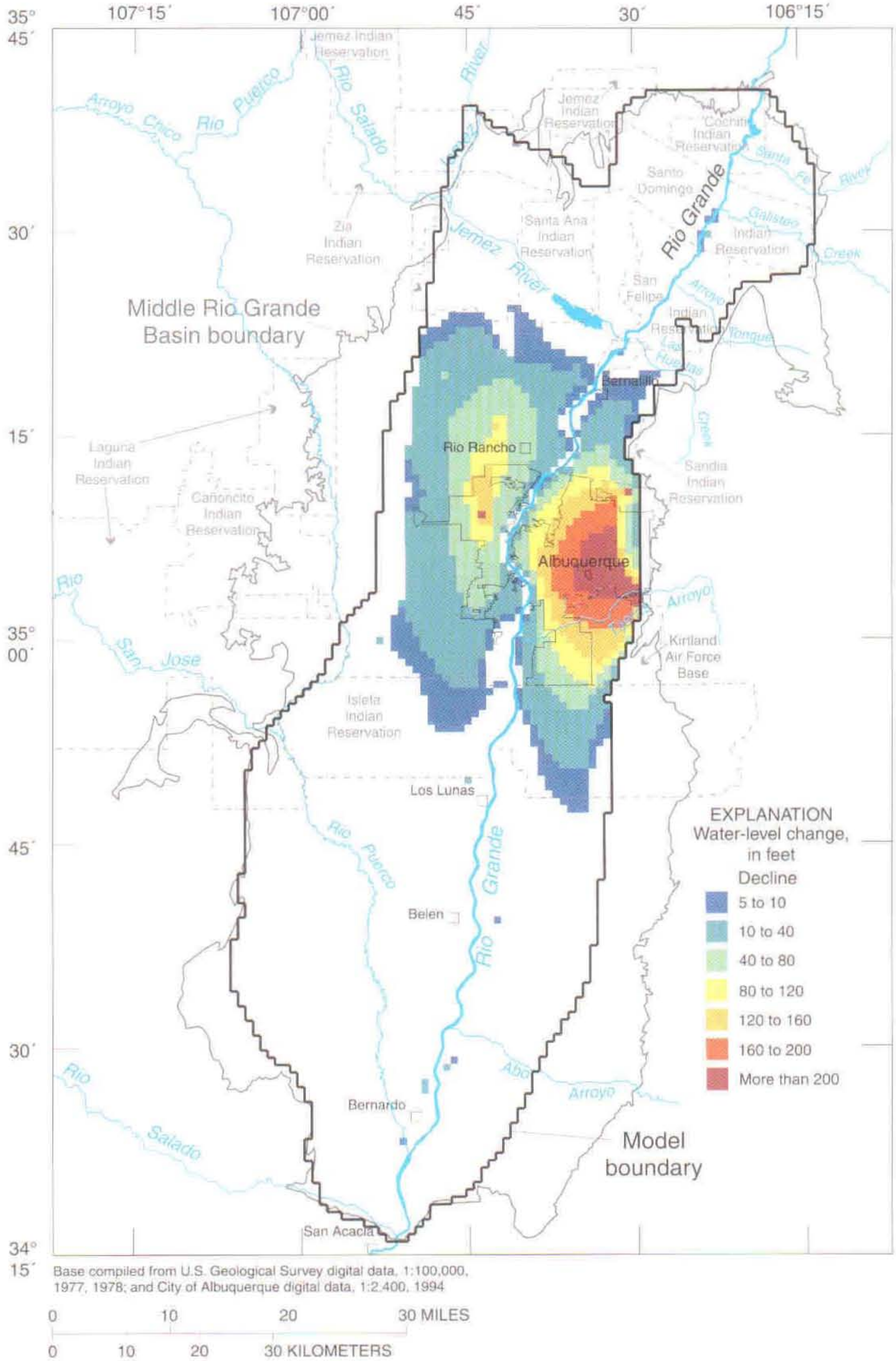

Figure 8. Simulated water-table change in the Middle Rio Grande Basin between steady state and 2040 for simulation I.

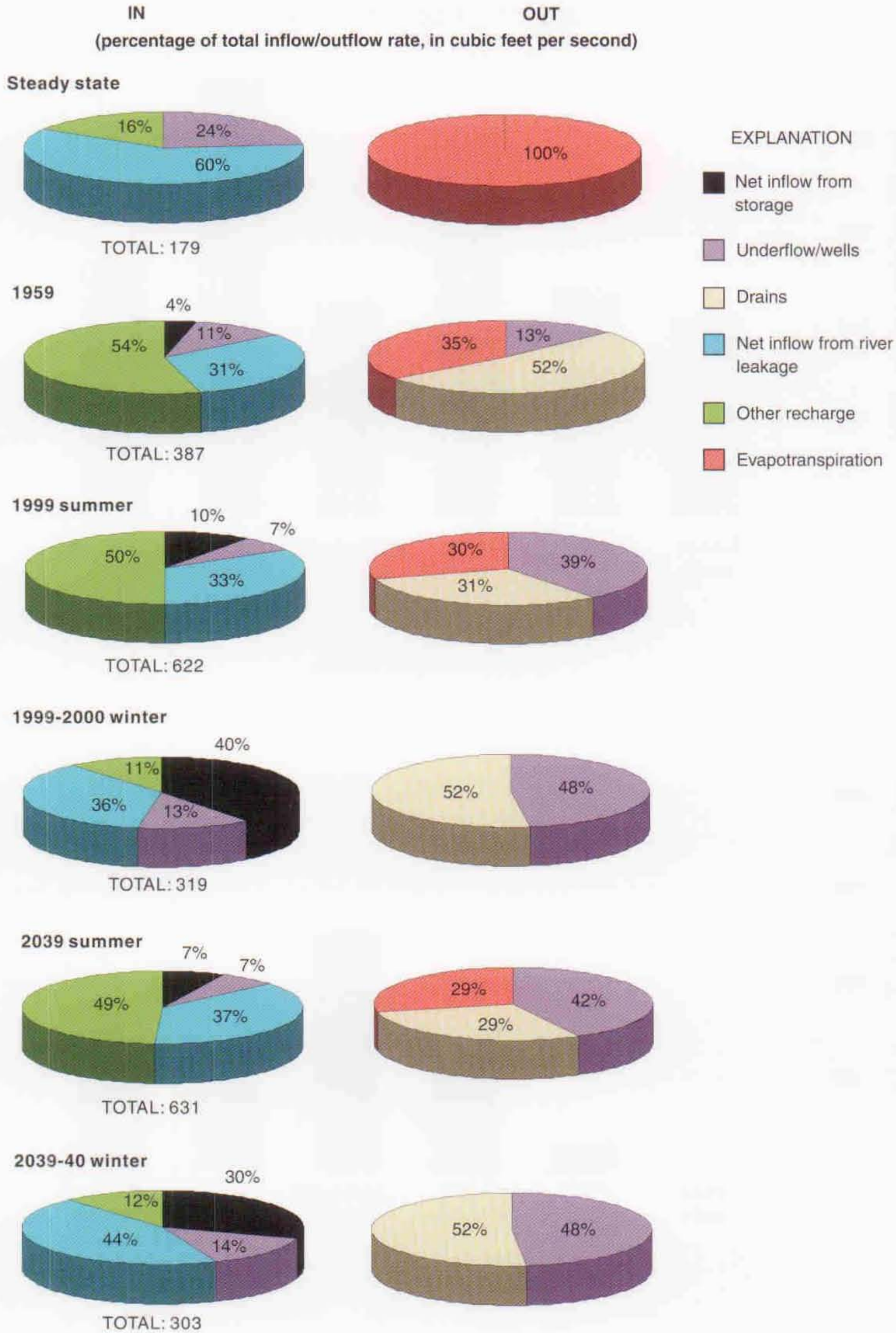

Figure 9. Simulated water budgets for the ground-water system through 2040 in simulation I.

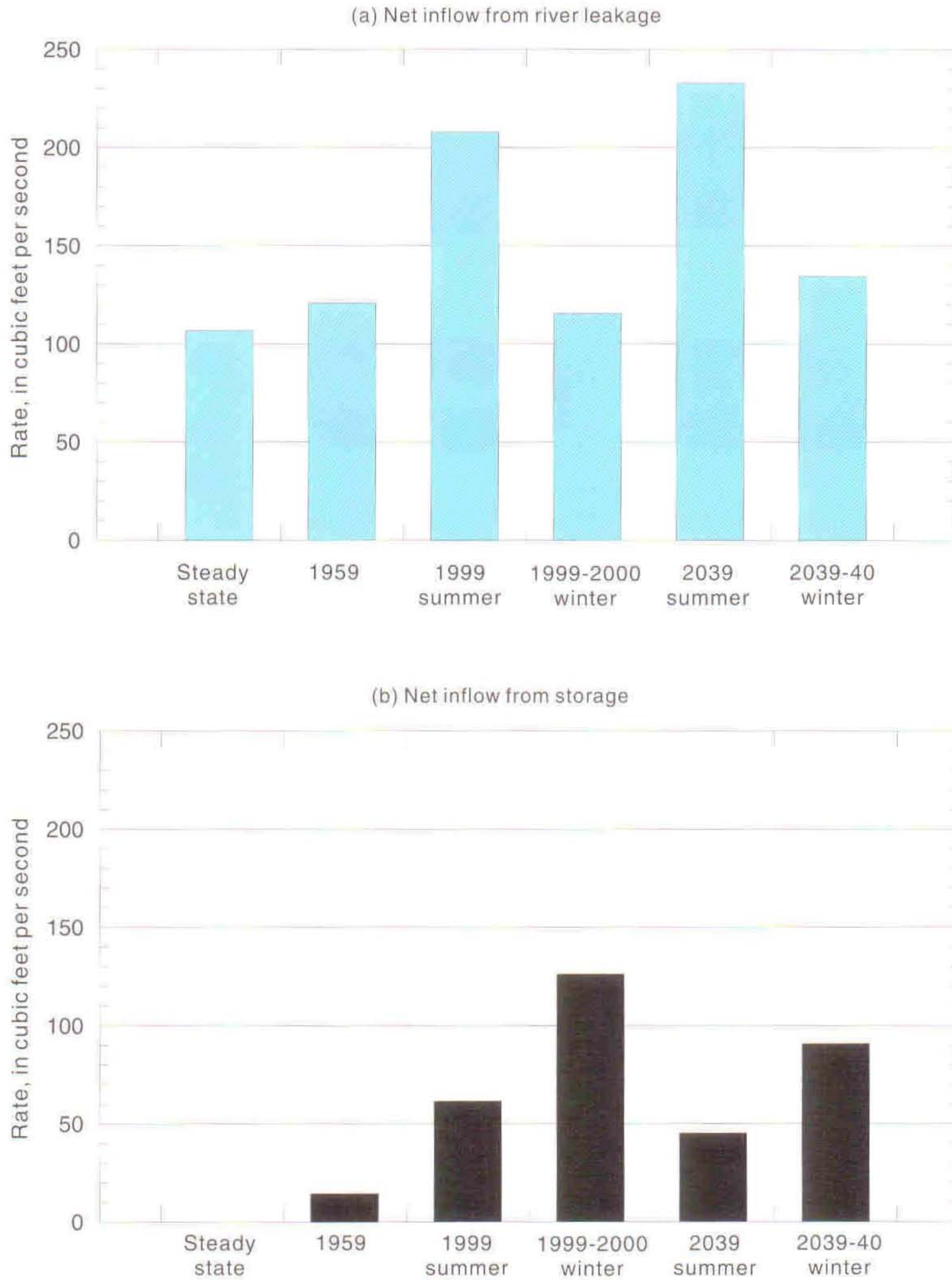

Figure 10. Simulated net inflow to the ground-water system in simulation I from (a) river leakage and (b) storage.

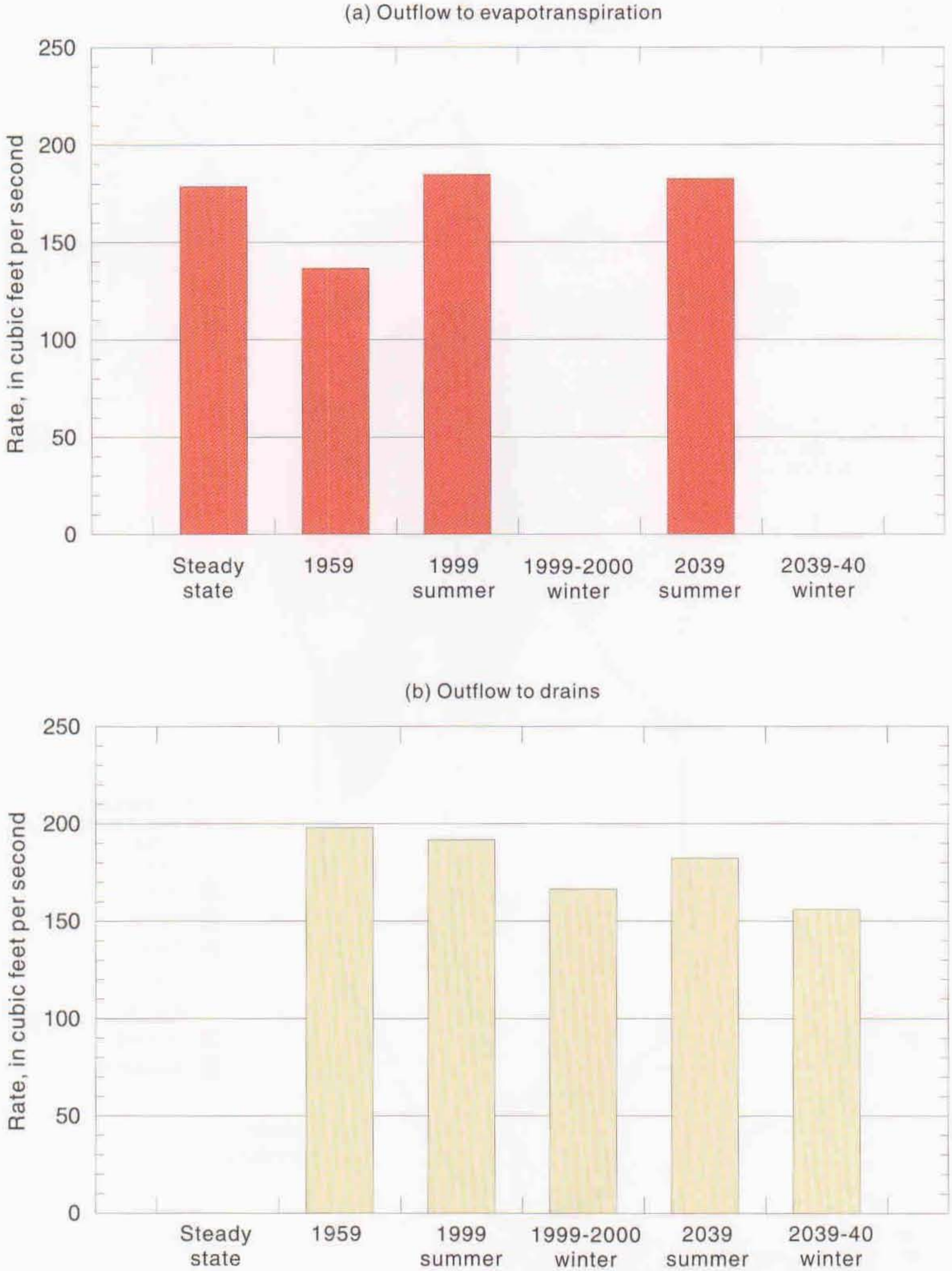

Figure 11. Simulated outflow from the ground-water system in simulation I from (a) evapotranspiration and (b) drains.

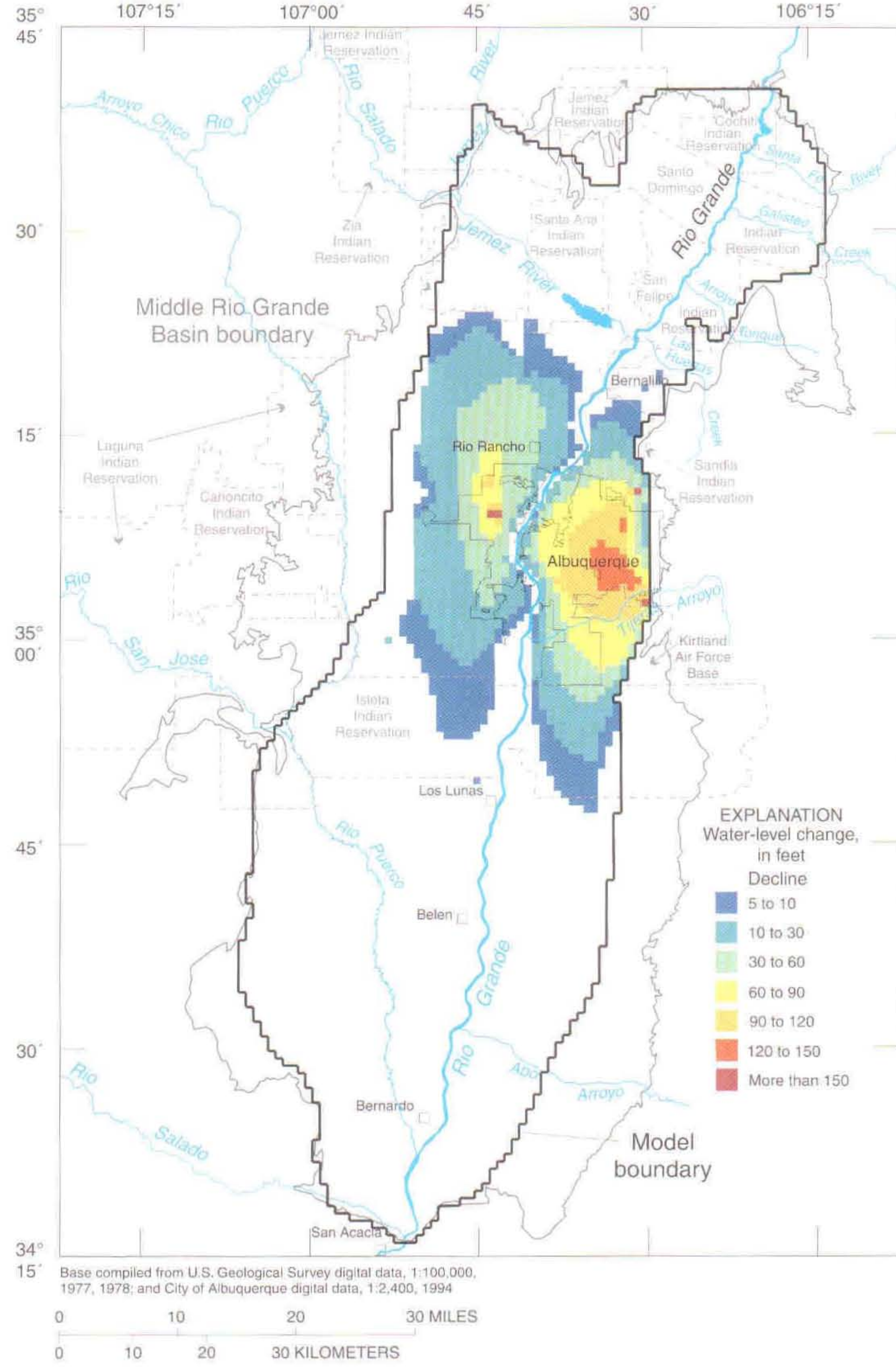

Figure 12. Simulated water-table change in the Middle Rio Grande Basin between 2000 and 2040 for simulation II.

city, with maximum water-table decline exceeding 280 feet (fig. 13). For both time ranges (2000-40 and predevelopment-2040), water-level decline in the production zone is of similar magnitude as water-table decline. As with simulation I, no model cells at the Rio Grande went dry during this simulation.

Compared with simulation I, simulation II shows a similar increase in the percentage of inflow to the ground-water system through net river leakage between 2000 and 2040 (fig. 14, compared with fig. 9). However, as a result of greater water-level decline and associated hydraulic gradients, the actual rate of inflow through net river leakage shows a larger increase for simulation II, equaling about 20 percent during the summer and 30 percent during the winter (fig. 15). Unlike simulation I, the net percentage and rate of contribution of water to the ground-water system from storage in simulation II increase between 2000 and 2040 for the summer months (figs. 14 and 15), probably because the additional recharge induced from the Rio Grande is not sufficient to replace all the ground water being removed by pumping. For the winter months, the net percentage and rate of contribution from storage show decreases for both simulations, but the decreases are smaller for simulation II than for simulation I (figs. 14 and 15). The outflow budget for simulation II indicates that losses through both evapotranspiration and drain flow decrease by about 5 to 8 percent between 2000 and 2040 (fig. 14), which corresponds to the increasing outflow of water from the system through pumping and the associated decline in the water table. Actual rates of loss through evapotranspiration and drain flow decrease by about 2 to 7 percent (fig. 16).

Simulation III—Reduced Pumping to Supplement Surface-Water Supply

Simulation III represents the scenario of small pumping by the City of Albuquerque to supplement the use of surface water for municipal supply through 2040. Between 2000 and 2040, the reduced pumping of simulation III results in continued water-level decline (over decline present in 2000) in some areas and water-level rise in others. Additional water-table decline occurs primarily along the western and eastern margins of Albuquerque, including across most of Rio Rancho to the northwest and Kirtland Air Force Base to the southeast (fig. 17), where municipal-water suppliers other than the City of Albuquerque were simulated as continuing to pump at year-2000 rates. The additional water-table decline in these areas is generally less than 60 feet in magnitude. The water table rises over much of the area of Albuquerque that is east of the Rio Grande as well as over a small area west of the river (fig. 18). The magnitude of water-table rise exceeds 25 feet in places and is greatest in the area of the Leyendecker, Charles Wells, and Thomas well fields, which is where some of the largest water-table declines had previously occurred. Water-level rise in the production zone of the aquifer is of a similar magnitude as water-table rise but is even more widespread (fig. 19). Simulated water levels indicate that water-table rise begins before 2010 and exceeds 50 feet in areas by 2020, but ceases before 2030 as projected pumping rates (fig. 5) continue to grow from a low around 2010 to meet increasing demand that cannot be supplied by surface water. This simulation using projected pumping reductions through 2040 indicates that total water-table decline since predevelopment is generally less than 110 feet west of the Rio Grande and less than 130 feet east of the river (fig. 20).

Between 2000 and 2040, this simulation with reduced pumping shows only a slight increase (1 percent) in the percentage of inflow to the ground-water system through net river leakage in the summer and essentially no change in the winter (fig. 21). The actual rate of inflow through net river leakage during this time period decreases by about 5 percent in the summer and 14 percent in the winter (fig. 22) because of the reduced hydraulic gradients associated with rising water levels. Similar to simulation I, the net percentage and rate of contribution of water to the system from storage during this time period decrease for both the summer and winter seasons (figs. 21 and 22), probably because net river inflow is sufficient to replace ground water removed by pumping. The actual net rate of inflow from storage decreases by about 63 percent during the summer and 18 percent during the winter (fig. 22). The outflow budget indicates that the loss through evapotranspiration increases by only about 2 percent between 2000 and 2040 (fig. 21); the actual rate of loss is nearly constant. Percentage losses through drains also increase between 2000 and 2040 for both the winter and summer seasons (fig. 21), whereas actual rates of loss are nearly constant. A slight increase in outflow from the system through evapotranspiration and drain flow is expected because plant roots and ground-water drains would intercept the higher water table over a larger area. The rate of outflow through pumping (and, consequently, the percentage of outflow through pumping) was decreased through model input.

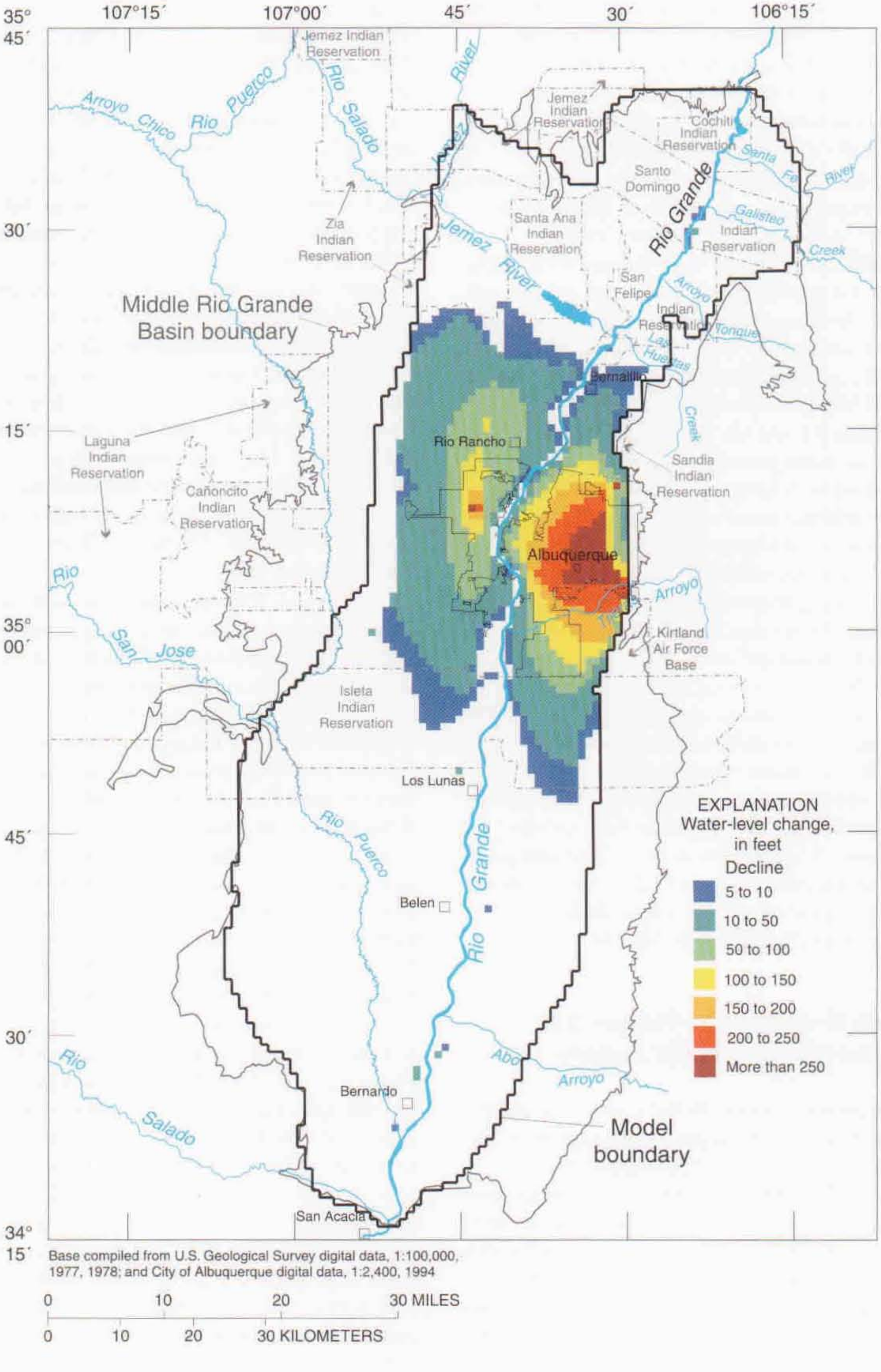

Figure 13. Simulated water-table change in the Middle Rio Grande Basin between steady state and 2040 for simulation II.

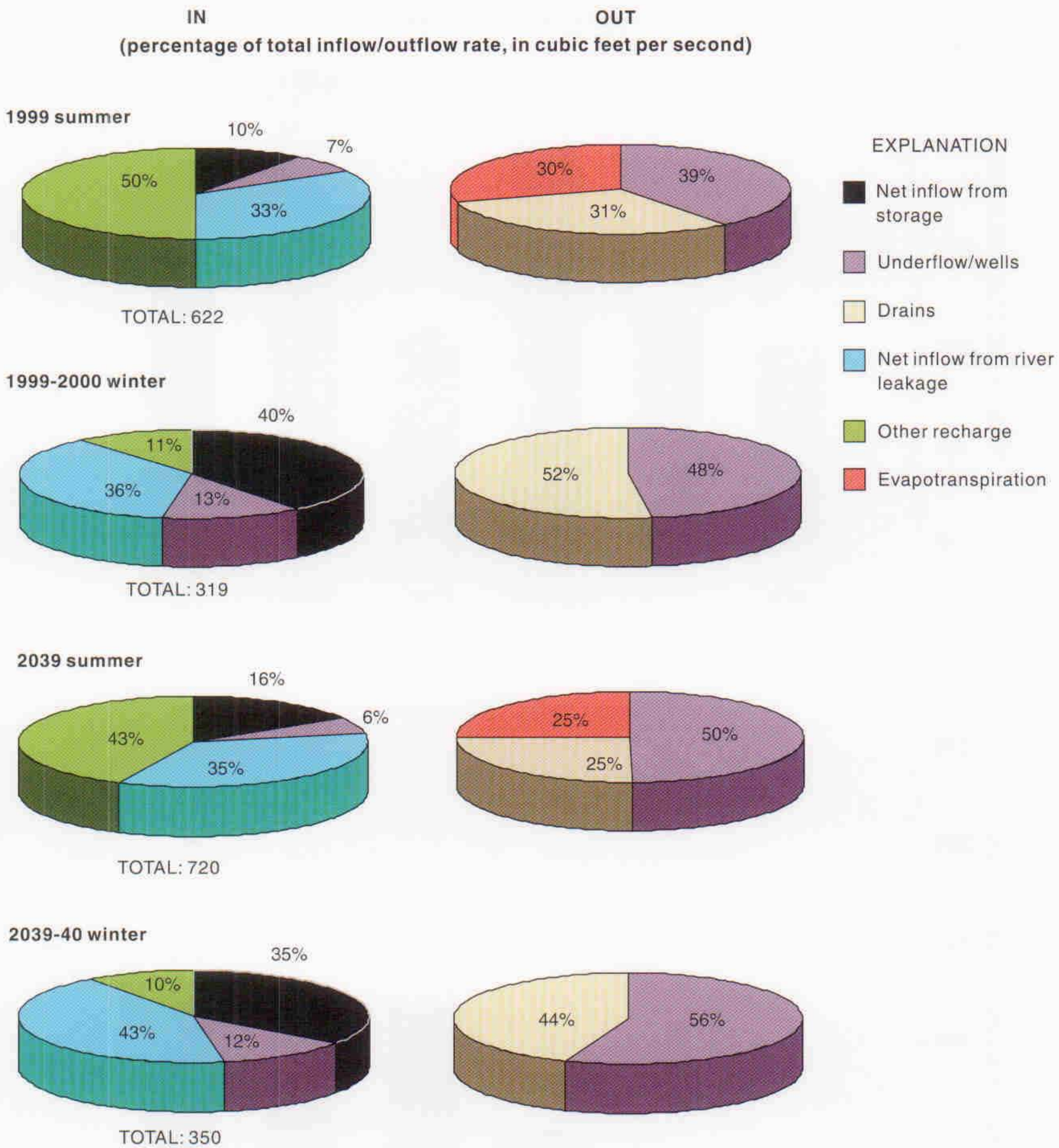

Figure 14. Simulated water budgets for the ground-water system through 2040 in simulation II.

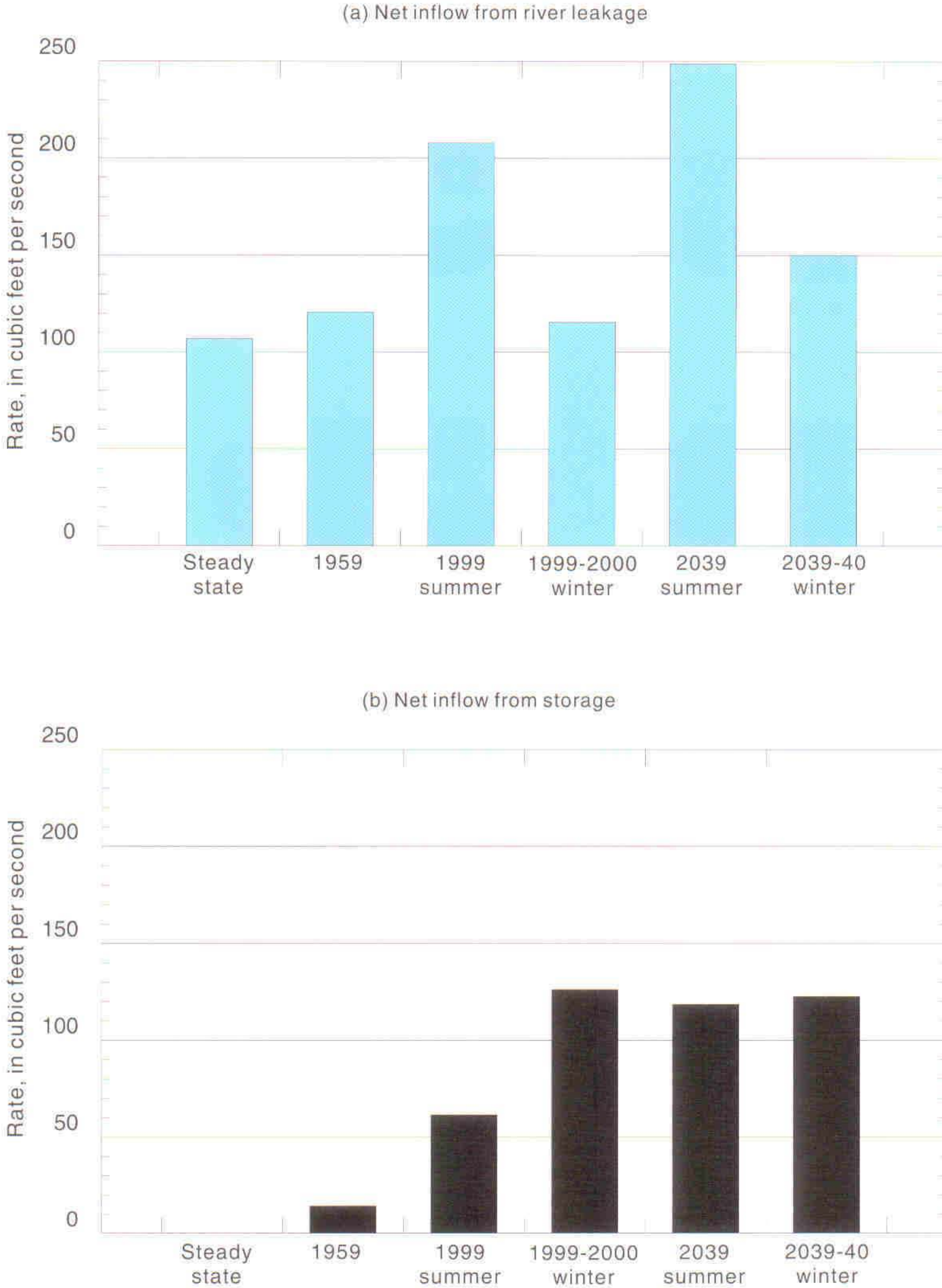

Figure 15. Simulated net inflow to the ground-water system in simulation II from (a) river leakage and (b) storage.

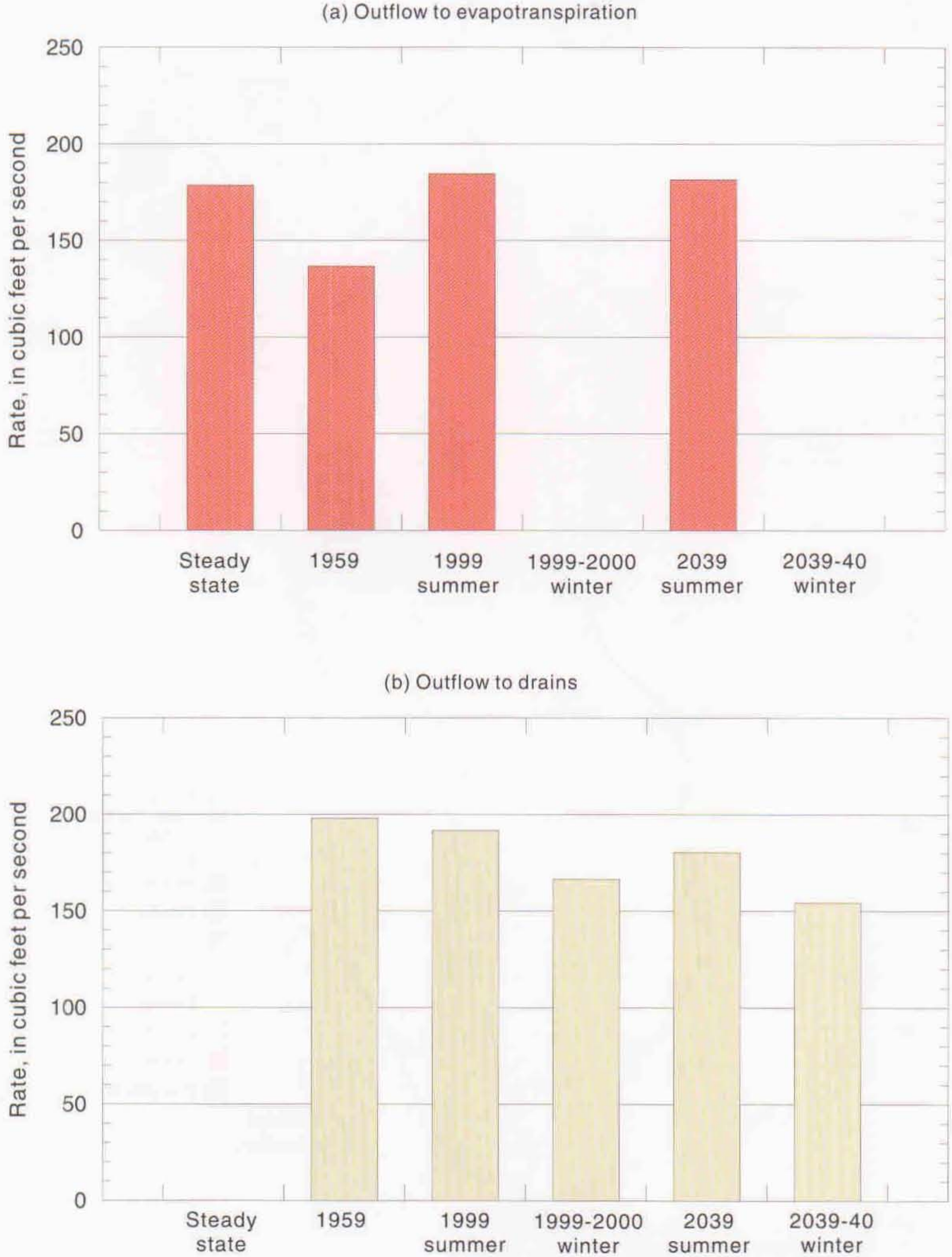

Figure 16. Simulated outflow from the ground-water system in simulation II from (a) evapotranspiration and (b) drains.

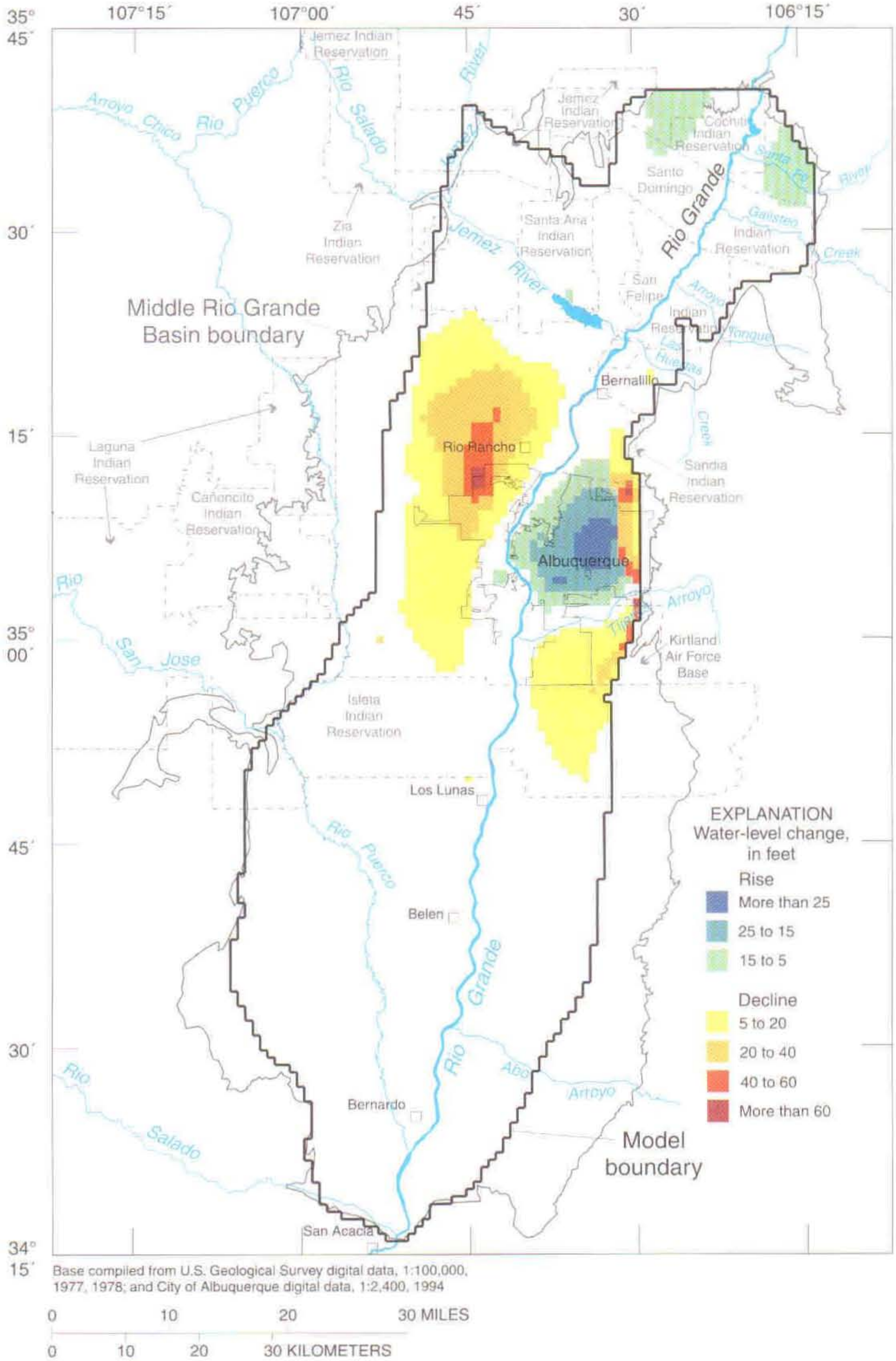

Figure 17. Simulated water-table change in the Middle Rio Grande Basin between 2000 and 2040 for simulation III.

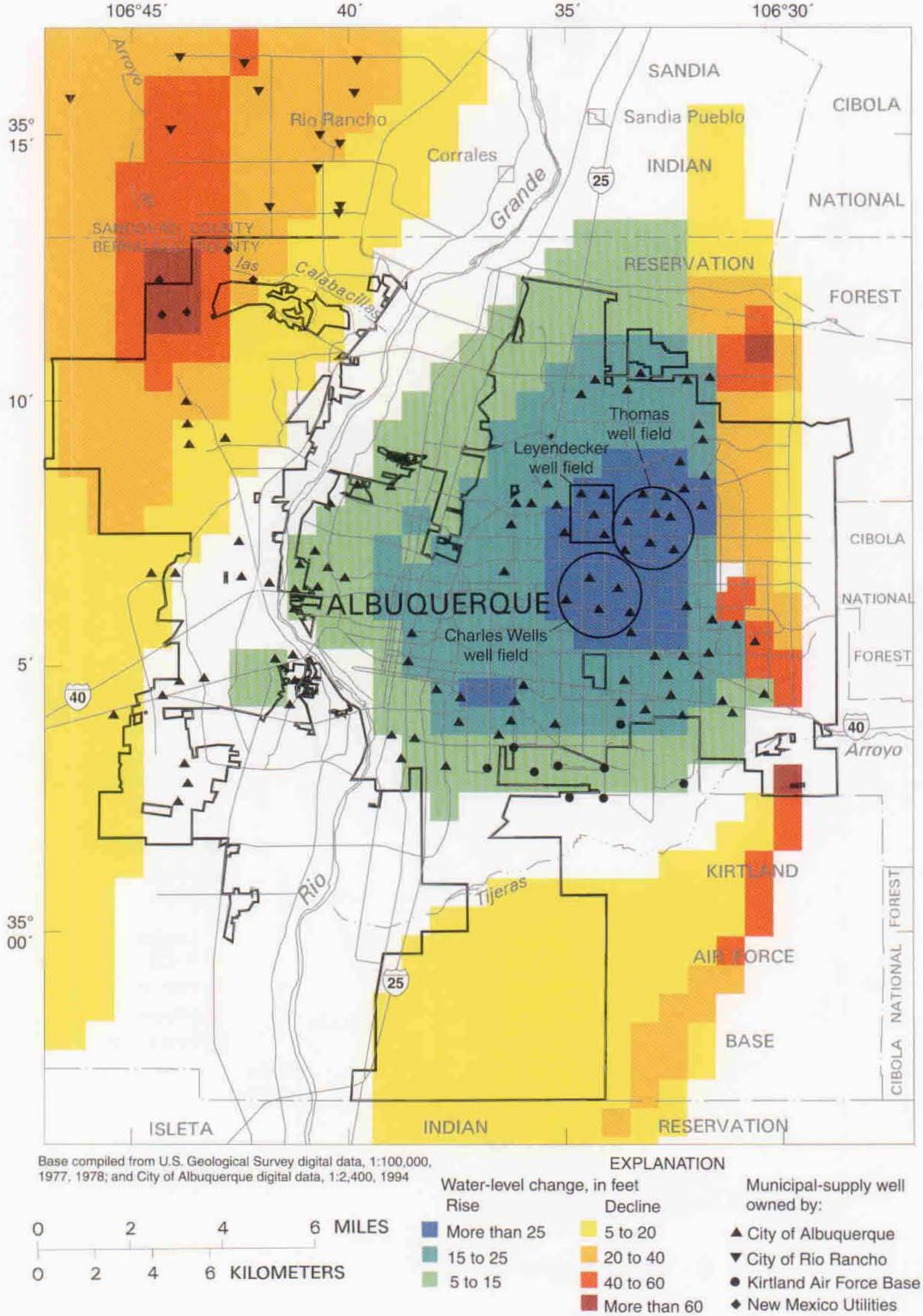

Figure 18. Simulated water-table change in the Albuquerque area between 2000 and 2040 for simulation III.

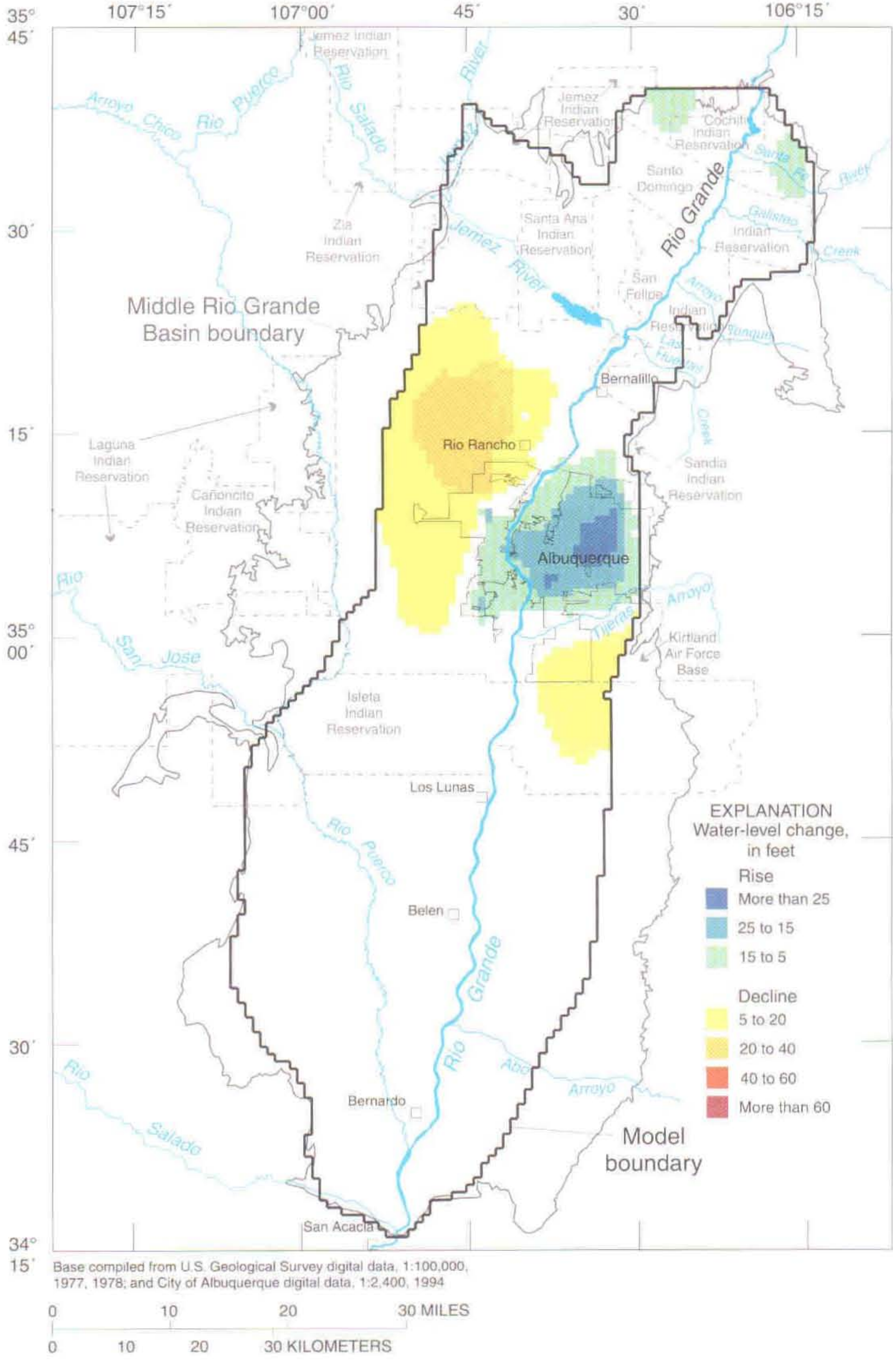

Figure 19. Simulated water-level change in the production zone (layer 5) between 2000 and 2040 for simulation III.

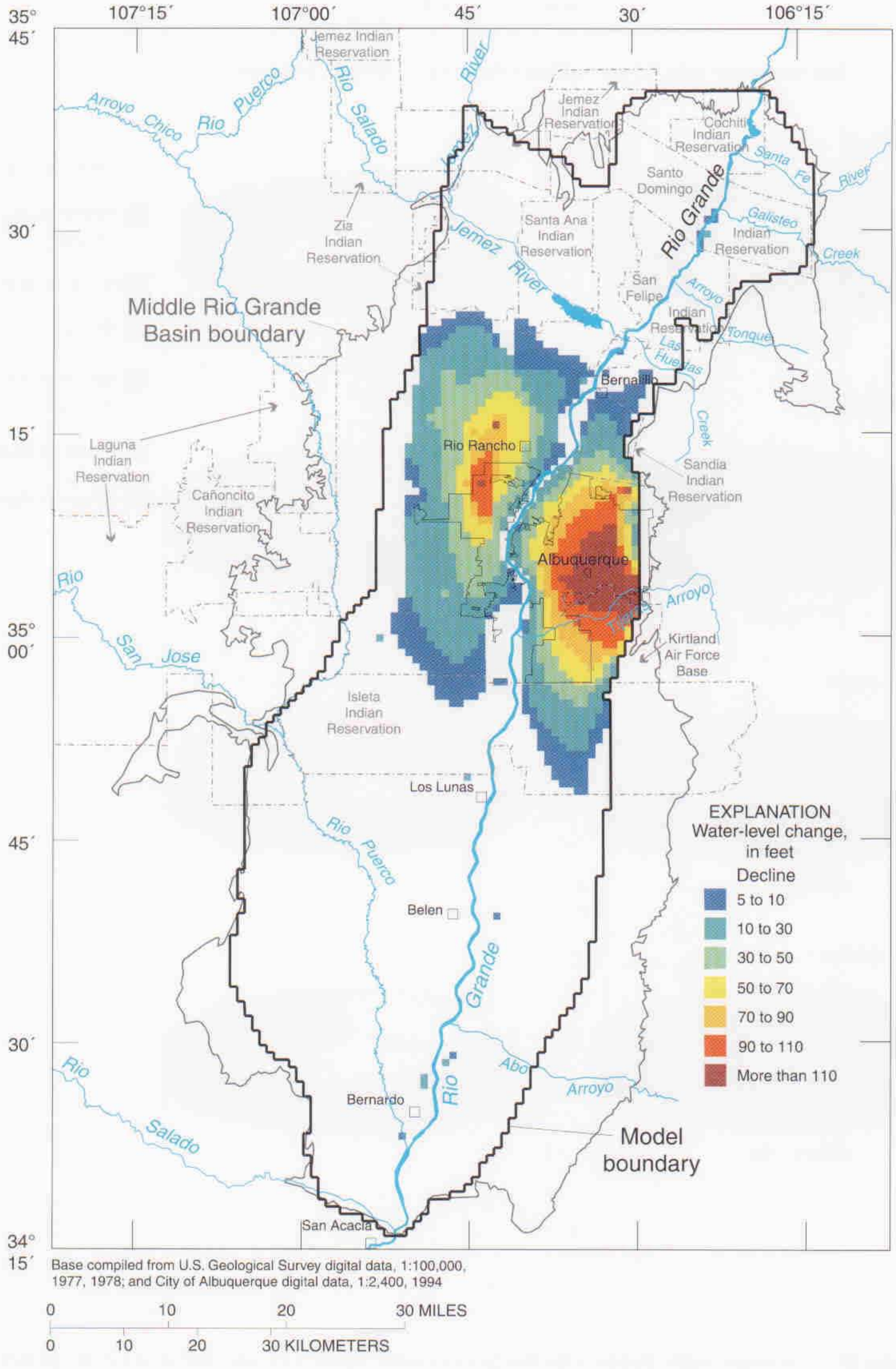

Figure 20. Simulated water-table change in the Middle Rio Grande Basin between steady state and 2040 for simulation III.

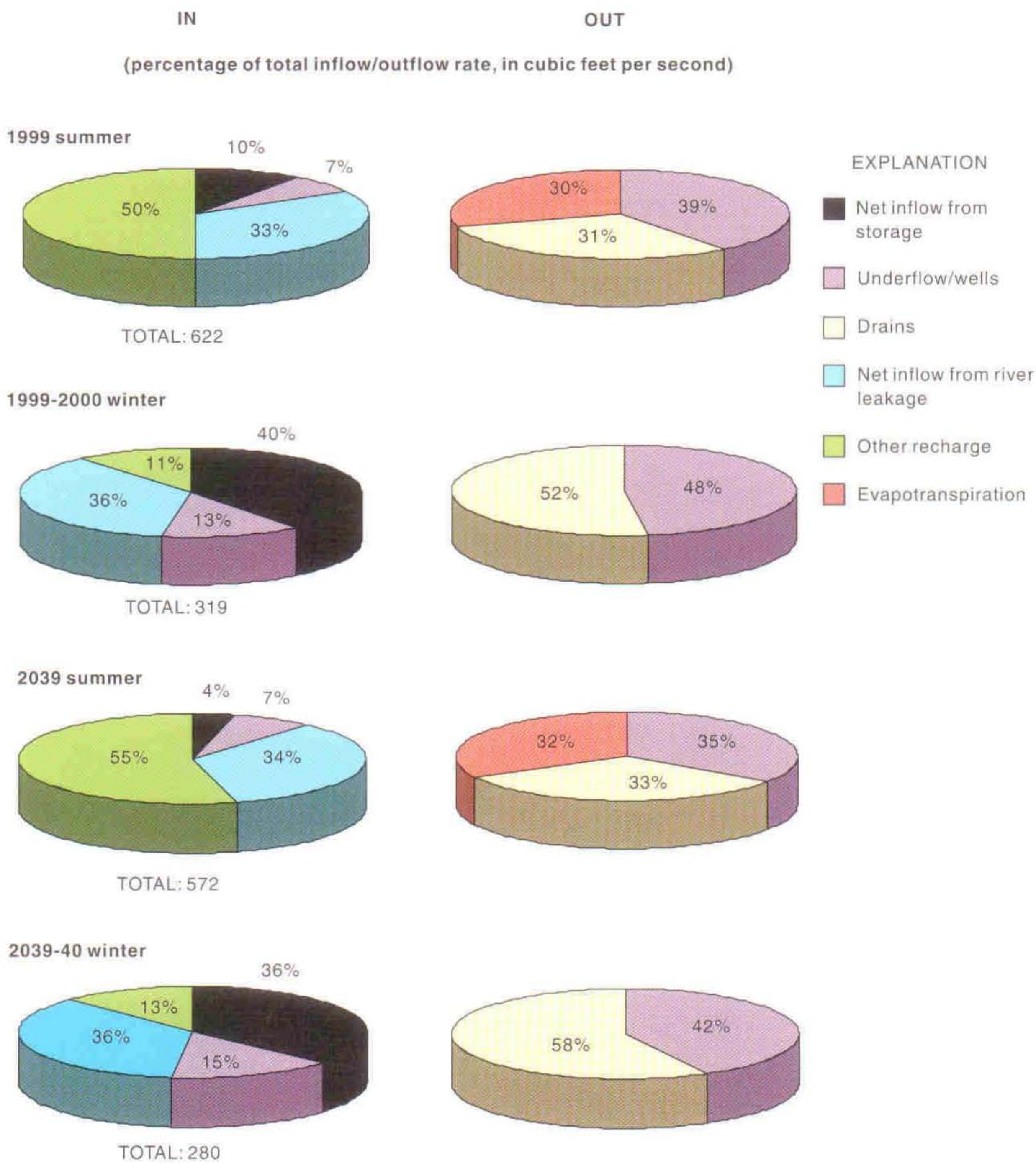

Figure 21. Simulated water budgets for the ground-water system in selected years in simulation III.

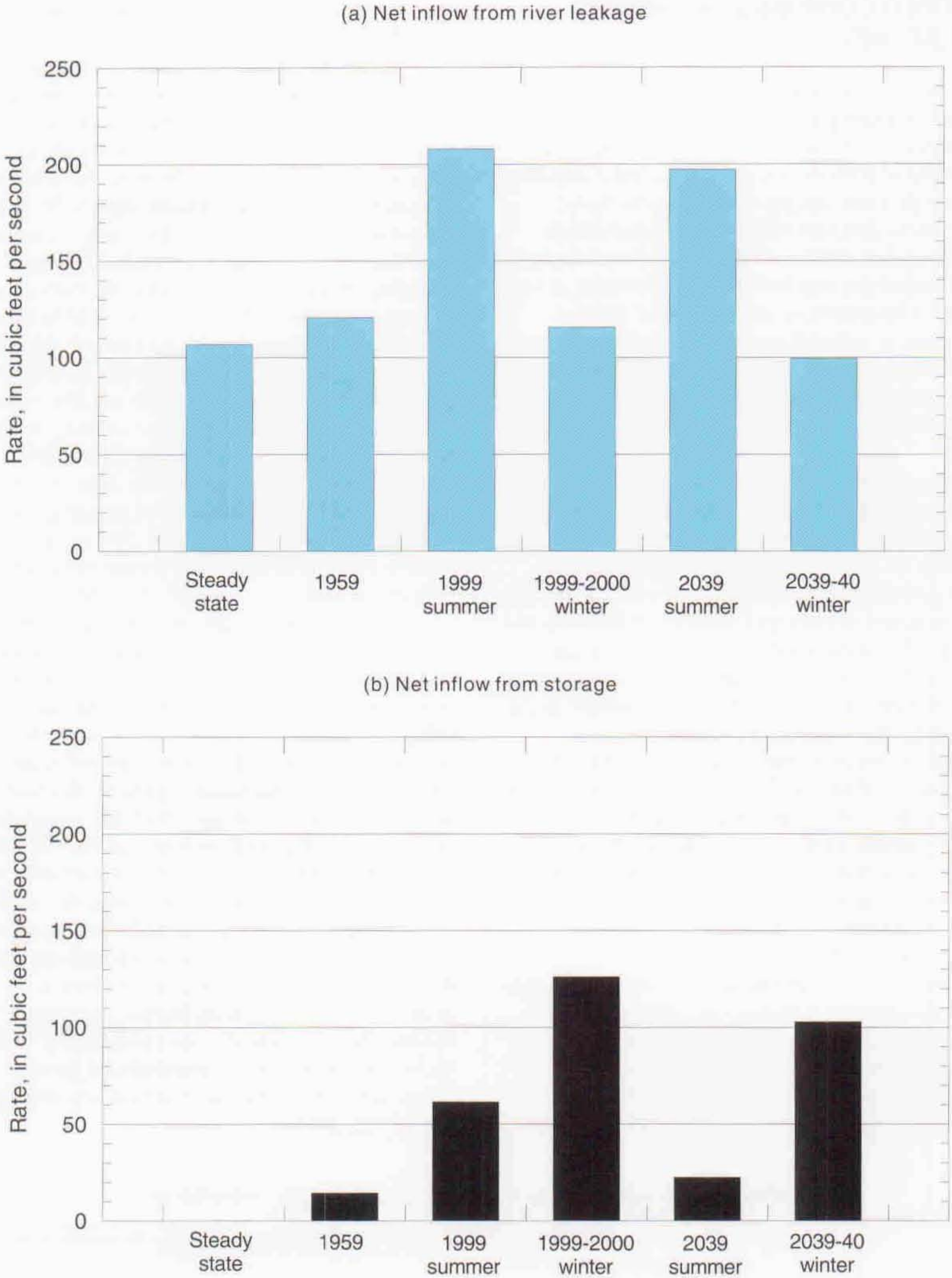

Figure 22. Simulated net inflow to the ground-water system in simulation III from (a) river leakage and (b) storage.

SELECTED COMPARISONS AMONG SIMULATIONS

Results of simulations I, II, and III indicate that the various pumping scenarios have substantially different effects on water levels in the Albuquerque area and on the contribution of each budget component to the overall water budget for the ground-water system. These different effects are summarized in table 1. Between 2000 and 2040, water-level declines in the Albuquerque area for continued pumping at year-2000 rates (simulation I) are as much as 100 feet greater than for reduced pumping (simulation III) (fig. 23). Water-level declines for increased pumping to meet all projected city demand (simulation II) are as much as 160 feet greater than for reduced pumping (fig. 24).

Compared with the other pumping scenarios, reduced pumping results in the depletion of much less ground water from aquifer storage between 2000 and 2040 (table 1). In simulation III, the net result of reduced pumping is replenishment of water in storage (that is, negative net storage) between about 2006 and 2020 (fig. 25), when pumping volumes are at their lowest (fig. 5). Between 2000 and 2040, the cumulative volume of water retained in or added to storage in the aquifer under the scenario of reduced pumping compared to continued pumping at year-2000 rates totals about 1,536,000 acre-feet (fig. 25a). This volume represents about 64 percent of the total difference in pumping volumes between simulations I and III (fig. 26a). For the scenario of reduced pumping compared with increased pumping to meet all city demand, the cumulative volume of water retained in or added to storage is about 2,257,000 acre-feet (fig. 25b), or about 69 percent of the total difference in pumping volumes between simulations II and III (fig. 26b). For simulation III relative to simulation I, the cumulative volume of water retained in or added to storage increases most rapidly between about 2006 and 2024 (fig. 27a); for simulation III relative to simulation II, the cumulative volume of water "saved" increases more steadily over time (fig. 27b).

The simulation III scenario of reduced city pumping also results in the depletion of much less surface water from the Rio Grande compared with the other pumping scenarios (fig. 28 and table 1). The volume of water retained in the river per year increases continually from about 2006 through 2020, at which time this volume remains fairly steady from year to year (fig. 28a). This pattern is probably related to changing hydraulic gradients near the river as a result of water-level rise. The cumulative volume of water retained in the river between 2000 and 2040 as a result of reduced compared with continued pumping totals about 731,000 acre-feet (figs. 28a and 29a) or about 30 percent of the total difference in pumping volumes between simulations I and III (fig. 26a). The cumulative volume retained in the river as a result of reduced compared with increased pumping totals about 872,000 acre-feet (figs. 28b and 29b) or about 26 percent of the total difference in pumping volumes between simulations II and III (fig. 26b).

Because the scenario of reduced city pumping results in higher water levels compared with the other pumping scenarios, more water is lost from the aquifer system to evapotranspiration and to the drain system (table 1). The cumulative volume of water lost to evapotranspiration under the scenario of reduced compared with continued pumping totals about 38,000 acre-feet between 2000 and 2040; the cumulative volume lost to the drain system is about 107,000 acre-feet. Under the scenario of reduced compared with increased pumping, about 43,000 acre-feet is lost to evapotranspiration and about 122,000 acre-feet is lost to the drain system. Increased evapotranspiration and drain flow constitute about 2 and 4 percent, respectively, of the total difference in pumping volumes between simulations I and III (fig. 26a) and about 1 and 4 percent, respectively, of the total difference in pumping volumes between simulations II and III (fig. 26b).

Table 1. Summary of major results for each model simulation

Simulation	95th percentile of water-table decline from steady state (in feet)	From 2000 to 2040, cumulative annualized volume (in acre-feet) of: Net inflow from river leakage	Net inflow from storage	Outflow to evapotranspiration	Outflow to drain flow
I (medium pumping)	162	5,498,000	2,146,000	3,351,000	5,132,000
II (large pumping)	199	5,638,000	2,867,000	3,346,000	5,117,000
III (small pumping)	101	4,766,000	610,000	3,389,000	5,239,000

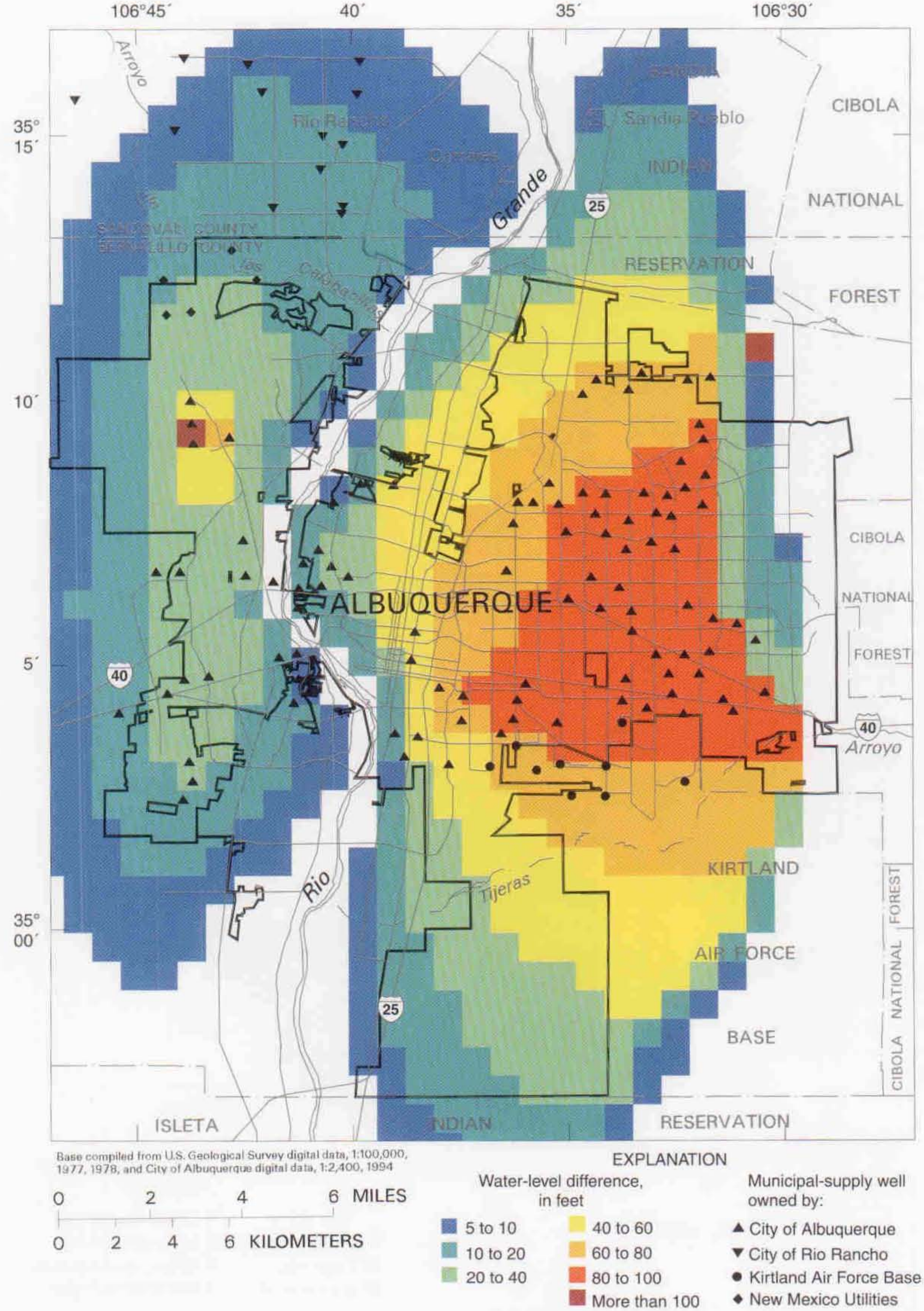

Figure 23. Difference between 2040 water levels for simulation III (reduced pumping) and simulation I (continued pumping at year-2000 rates). Simulation III water levels are substantially higher.

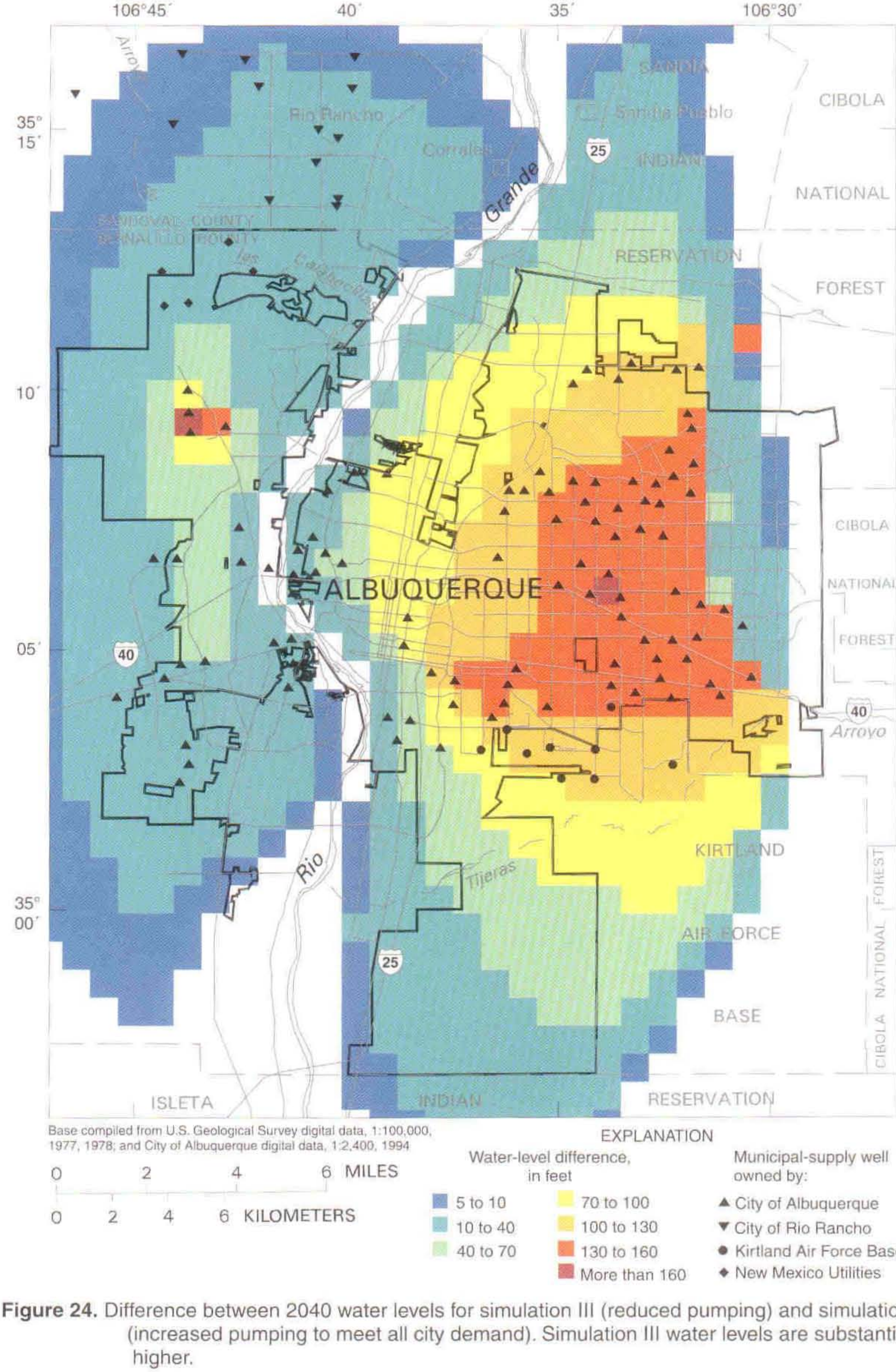

Figure 24. Difference between 2040 water levels for simulation III (reduced pumping) and simulation II (increased pumping to meet all city demand). Simulation III water levels are substantially higher.

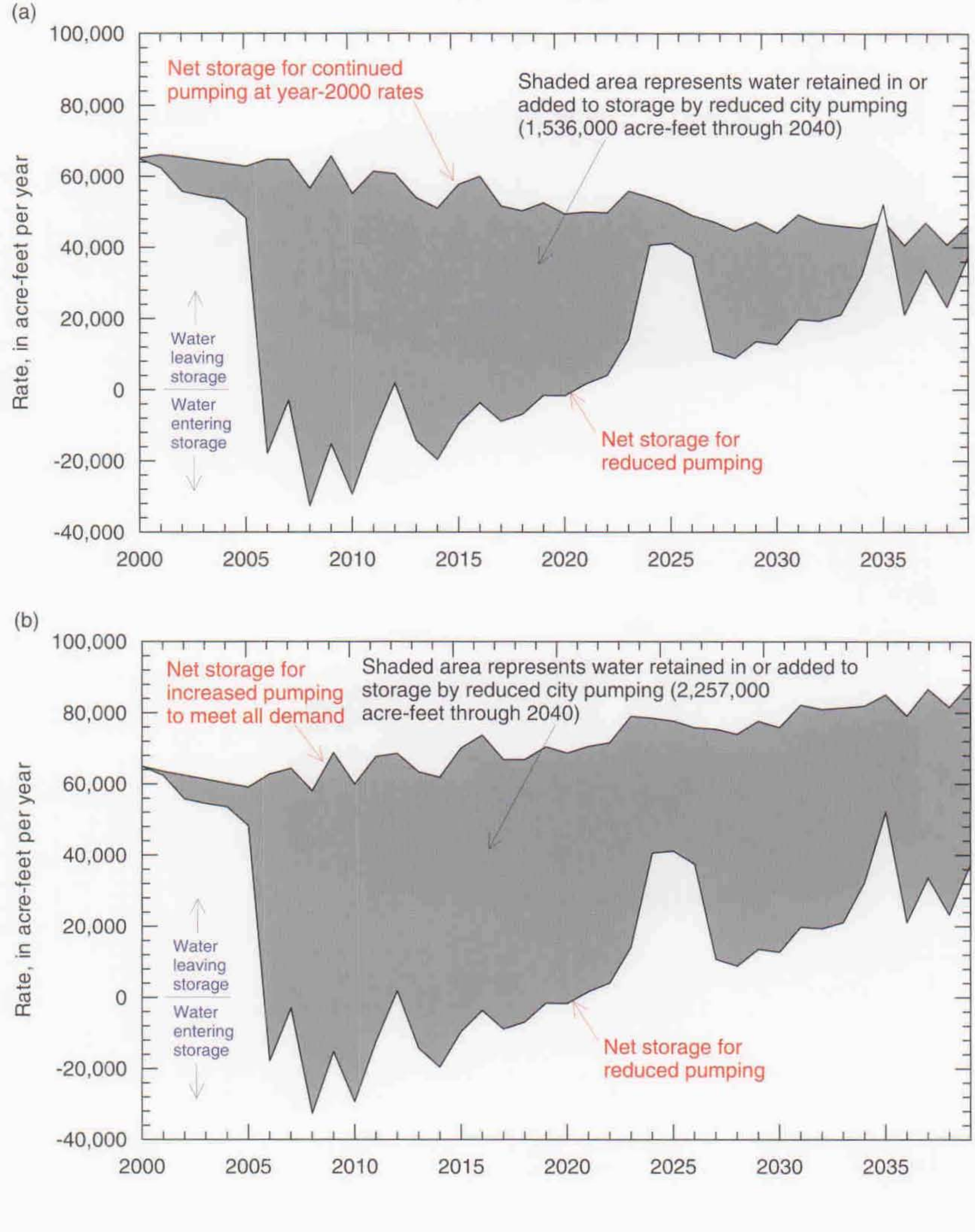

Figure 25. Comparison of annualized storage rates for scenarios of reduced city pumping to (a) continued pumping at year-2000 rates and (b) increased pumping to meet all demand.

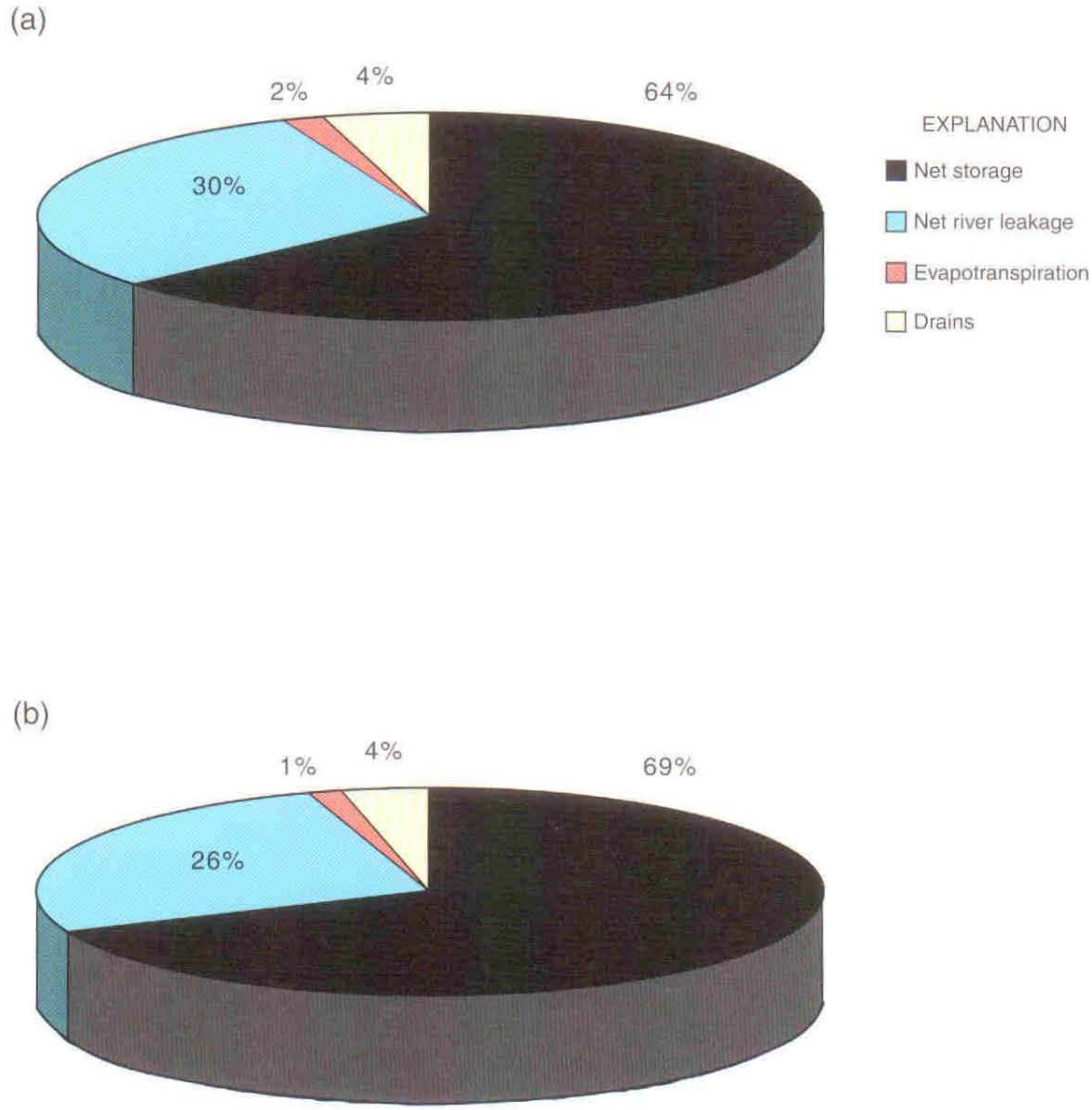

Figure 26. Simulated distribution among budget components of the difference in pumping volumes between (a) simulations I and III and (b) simulations II and III.

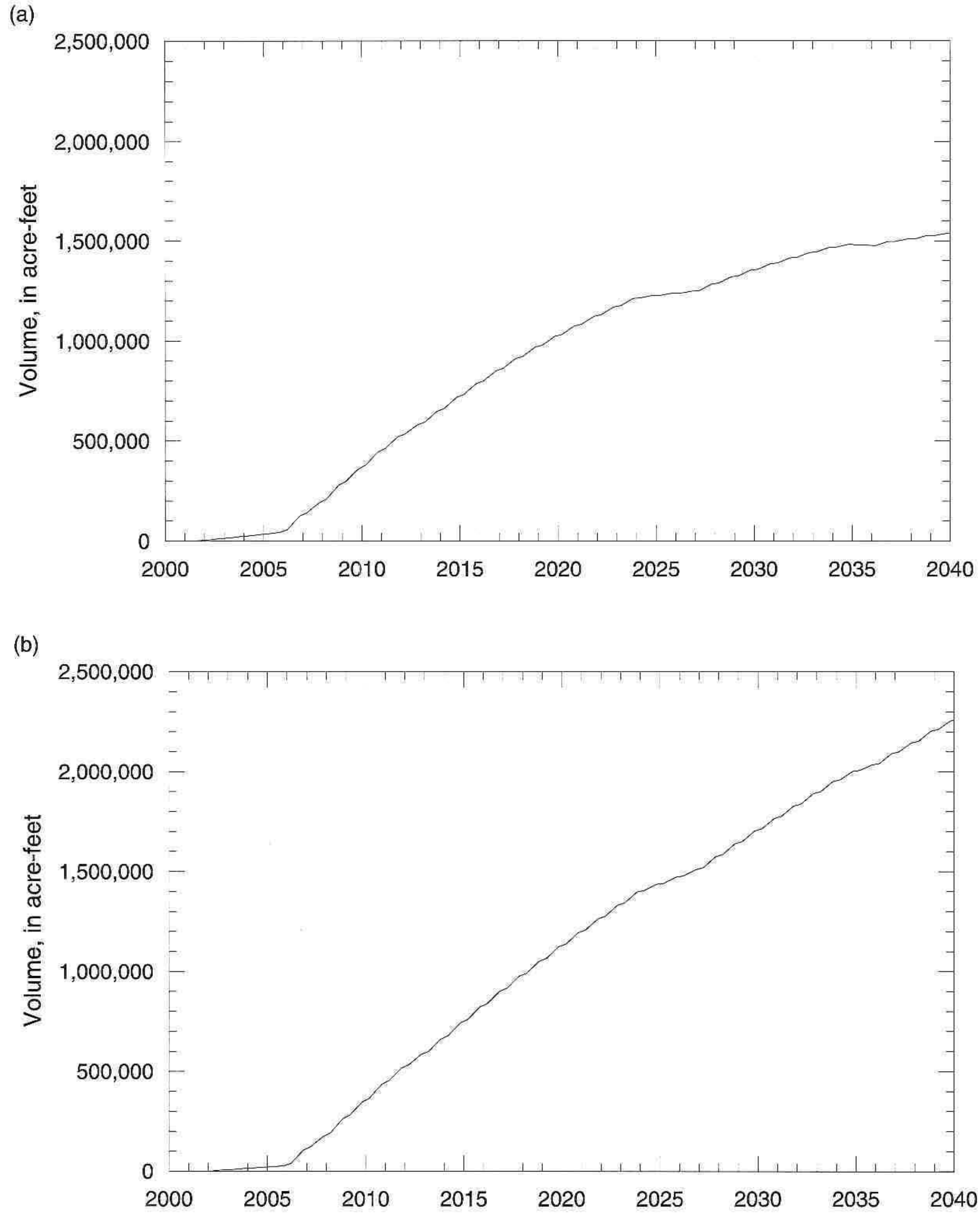

Figure 27. Cumulative volume of water retained in or added to storage by reduced city pumping compared to (a) continued pumping at year-2000 rates and (b) increased pumping to meet all demand.

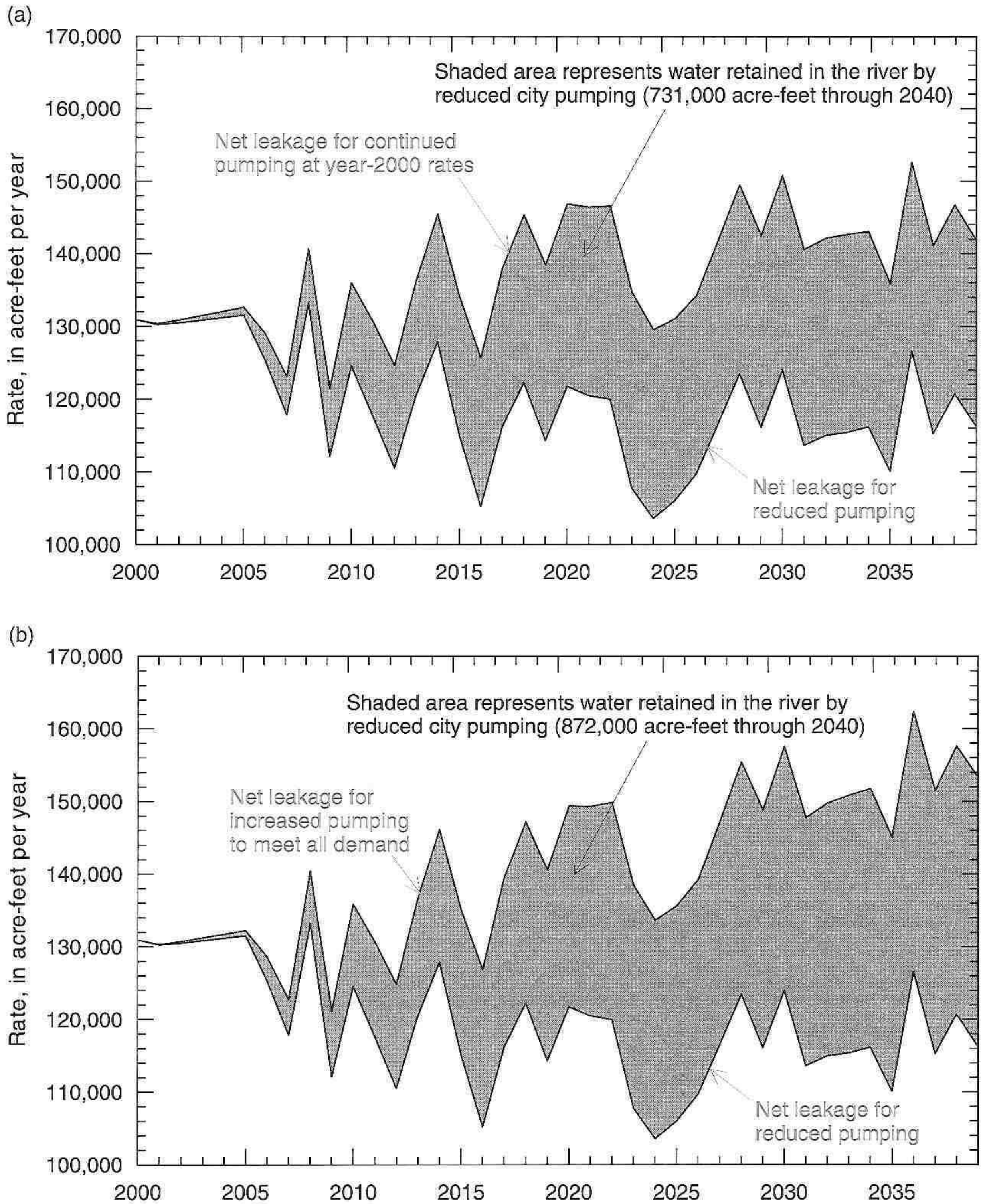

Figure 28. Comparison of annualized rates of net river leakage for scenarios of reduced city pumping to (a) continued pumping at year-2000 rates and (b) increased pumping to meet all demand.

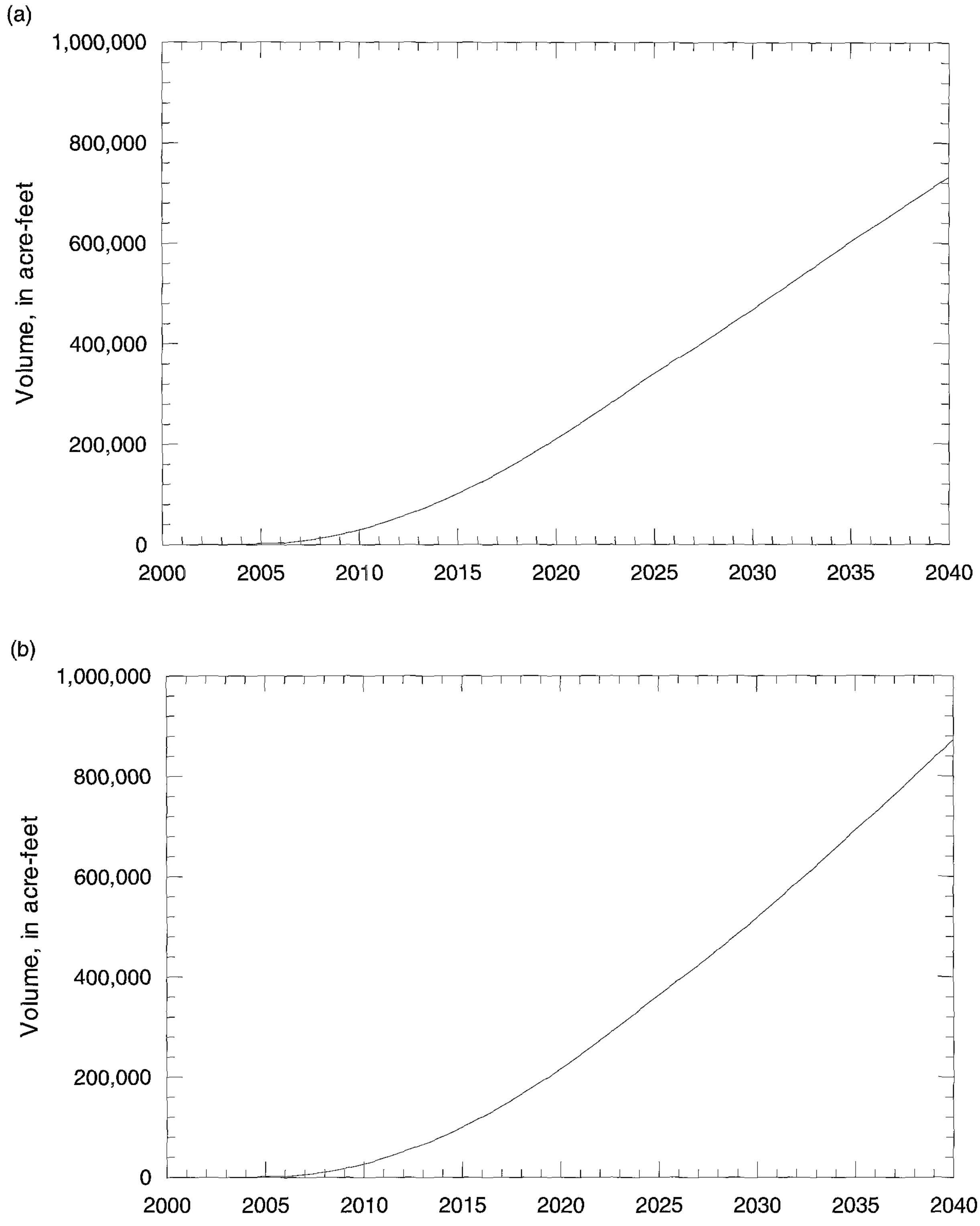

Figure 29. Cumulative volume of water retained in the river by reduced city pumping compared to (a) continued pumping at year-2000 rates and (b) increased pumping to meet all demand.

SUMMARY

The model developed by McAda and Barroll for the Santa Fe Group aquifer system of the Middle Rio Grande Basin was used to simulate future conditions in the aquifer for three different scenarios of ground-water pumping by the City of Albuquerque through the year 2040. For simulation I, city pumping was maintained at the year-2000 rate for each subsequent year (medium ground-water use). For simulation II, pumping was adjusted to equal the total city water demand that a City of Albuquerque consultant projected for each year through 2040 (high ground-water use). For simulation III, pumping was adjusted to equal just the portion of projected demand to be supplied by ground water once surface water begins to be delivered to city customers (low ground-water use). Whereas water levels in all three simulations decline between 2000 and 2040 in some areas around Albuquerque, water levels in simulation III also rise over large areas. In simulation III, water levels decline as much as 100 feet less than in simulation I and 160 feet less than in simulation II.

In addition to smaller water-level declines, the reduced pumping of simulation III results in substantially smaller inflow to the ground-water system from aquifer storage and river leakage than either simulation I or II. Whereas the rate of inflow of river leakage to the aquifer system between 2000 and 2040 increases by 12 percent or more for simulations I and II, it decreases by 5 percent or more for simulation III. The cumulative retention of water in the river as a result of reduced pumping is 731,000 acre-feet as compared to continued pumping at year-2000 quantities and 872,000 acre-feet as compared to increased pumping to meet all city water demand. The cumulative retention of ground water in storage in simulation III is 1,536,000 acre-feet as compared to simulation I and 2,257,000 acre-feet as compared to simulation II. Although the reduced pumping of simulation III results in a slight increase in loss of ground water to evapotranspiration and drain flow between 2000 and 2040, this loss totals only 5 to 6 percent of the difference in the volume of ground-water pumping between simulation III and either of the other simulations. These simulations indicate that reduced ground-water pumping by the City of Albuquerque through 2040 would have beneficial effects on the regional ground-water system, including substantially reduced water-level declines, increased aquifer storage, and reduced infiltration of surface water from the Rio Grande.

REFERENCES

Barroll, Peggy, 2001, Documentation of the administrative groundwater model for the Middle Rio Grande Basin: New Mexico Office of the State Engineer, Technical Services Unit, Hydrology Bureau Report 99-3, variously paged.

Bartolino, J.R., ed., 1997, U.S. Geological Survey Middle Rio Grande Basin Study—Proceedings of the First Annual Workshop, Denver, Colorado, November 12-14, 1996: U.S. Geological Survey Open-File Report 97-116, 91 p.

———ed., 1999, U.S. Geological Survey Middle Rio Grande Basin Study—Proceedings of the Third Annual Workshop, Albuquerque, New Mexico, February 24-25, 1999: U.S. Geological Survey Open-File Report 99-203, 95 p.

Bartolino, J.R., and Cole, J.C., 2002, Ground-water resources of the Middle Rio Grande Basin, New Mexico: U.S. Geological Survey Circular 1222, 132 p.

Bexfield, L.M., and Anderholm, S.K., 2002, Estimated water-level declines in the Santa Fe Group aquifer system in the Albuquerque area, central New Mexico, predevelopment to 2002: U.S. Geological Survey Water-Resources Investigations Report 02-4233, 1 sheet.

Bexfield, L.M., Lindberg, W.E., and Anderholm, S.K., 1999, Summary of water-quality data for City of Albuquerque drinking-water supply wells, 1988-97: U.S. Geological Survey Open-File Report 99-195, 138 p.

Bjorklund, L.J., and Maxwell, B.W., 1961, Availability of ground water in the Albuquerque area, Bernalillo and Sandoval Counties, New Mexico: New Mexico State Engineer Technical Report 21, 117 p.

City of Albuquerque, 2002, Water quality—Our water source: City of Albuquerque data available on the World Wide Web, accessed July 30, 2002, at URL *http://www.cabq.gov/waterquality/sources.html.*

Cole, J.C., ed., 2001, U.S. Geological Survey Middle Rio Grande Basin Study—Proceedings of the Fourth Annual Workshop, Albuquerque, New Mexico, February 15-16, 2000: U.S. Geological Survey Open-File Report 00-488, 51 p.

Harbaugh, A.W., Banta, E.R., Hill, M.C., and McDonald, M.G., 2000, MODFLOW-2000, the U.S. Geological Survey modular ground-water model—User guide to modularization concepts and the ground-water flow process: U.S. Geological Survey Open-File Report 00-92, 121 p.

Hawley, J.W., and Haase, C.S., 1992, Hydrogeologic framework of the northern Albuquerque Basin: Socorro, New Mexico Bureau of Mines and Mineral Resources Open-File Report 387, variously paged.

Kelley, V.C., 1977, Geology of Albuquerque Basin, New Mexico: Socorro, New Mexico Bureau of Mines and Mineral Resources Memoir 33, 60 p.

Kernodle, J.M., 1998, Simulation of ground-water flow in the Albuquerque Basin, central New Mexico, 1901-95, with projections to 2020 (Supplement two to U.S. Geological Survey Water-Resources Investigations Report 94-4251): U.S. Geological Survey Open-File Report 96-209, 54 p.

Kernodle, J.M., McAda, D.P., and Thorn, C.R., 1995, Simulation of ground-water flow in the Albuquerque Basin, central New Mexico, 1901-1994, with projections to 2020: U.S. Geological Survey Water-Resources Investigations Report 94-4251, 114 p.

Lozinsky, R.P., 1988, Stratigraphy, sedimentology, and sand petrology of the Santa Fe Group and pre-Santa Fe Group Tertiary deposits in the Albuquerque Basin, central New Mexico: Socorro, New Mexico Institute of Mining and Technology, Ph.D. dissertation, 298 p.

McAda, D.P., and Barroll, Peggy, 2002, Simulation of ground-water flow in the Middle Rio Grande Basin between Cochiti and San Acacia, New Mexico: U.S. Geological Survey Water-Resources Investigations Report 02-4200, 72 p.

Russell, L.R., and Snelson, S., 1990, Structural style and tectonic evolution of the Albuquerque Basin segment of the Rio Grande Rift, *in* Pinet, B., and Bois, C., eds., The potential of deep seismic profiling for hydrocarbon exploration: Paris, Editions Technip, French Petroleum Institute Research Conference Proceedings, p. 175-207.

Slate, J.L., ed., 1998, U.S. Geological Survey Middle Rio Grande Basin Study—Proceedings of the Second Annual Workshop, Albuquerque, New Mexico, February 10-11, 1998: U.S. Geological Survey Open-File Report 98-337, 91 p.

Thorn, C.R., McAda, D.P., and Kernodle, J.M., 1993, Geohydrologic framework and hydrologic conditions in the Albuquerque Basin, central New Mexico: U.S. Geological Survey Water-Resources Investigations Report 93-4149, 106 p.

Tiedeman, C.R., Kernodle, J.R., and McAda, D.P., 1998, Application of nonlinear-regression methods to a ground-water flow model of the Albuquerque Basin, New Mexico: U.S. Geological Survey Water-Resources Investigations Report 98-4172, 90 p.

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